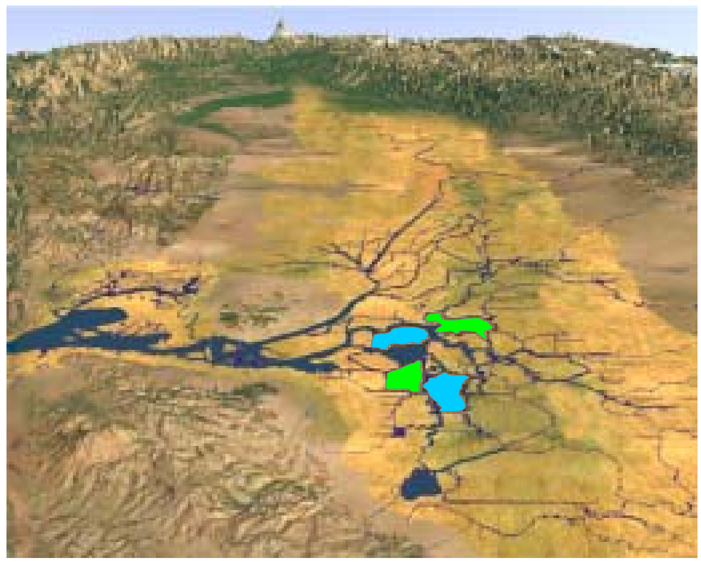
INTEGRATED STORAGE INVESTIGATIONS

IN-DELTA STORAGE PROGRAM
STATE FEASIBILITY STUDY
DRAFT REPORT ON WATER QUALITY



CALIFORNIA BAY-DELTA AUTHORITY

DEPARTMENT OF WATER RESOURCES · STATE OF CALIFORNIA

Division of Planning and Local Assistance
Department of Water Resources

July 2003

ORGANIZATION

FOREWORD

We acknowledge the technical assistance provided by Reclamation in carrying out the role of federal lead agency for the CALFED Integrated Storage Investigations. Reclamation has not yet completed a full review of the State Feasibility Study reports. Reclamation will continue to provide technical assistance through the review of the State Feasibility Study reports and DWR will work with Reclamation to incorporate comments and recommendations in the final reports.

State of California
Gray Davis, Governor

The Resources Agency
Mary D. Nichols, Secretary for Resources

California Bay-Delta Authority	**Department of Water Resources**	
Patrick Wright, Director	Michael J. Spear, Interim Director	Stephen Verigin, Acting Chief Deputy Director
Wendy Halverson-Martin, Chief Deputy Director	Jonas Minton, Deputy Director	Tom Glover, Deputy Director
	Lucinda Chipponeri, Deputy Director	Peggy Bernardy, Chief Counsel
	Mark Cowin, Chief, Division of Planning and Local Assistance	

This report was prepared under the direction of

Division of Planning and Local Assistance
Stephen S. Roberts, Chief
Surface Storage Investigations Branch
Tirath Pal Sandhu, Project Manager
In-Delta Storage Program

With Major Contributions from

Engineering Investigations Team	**Environmental Evaluations Team**
Jeremy Arrich, Senior Engineer, WR	Leslie Pierce, Senior Environmental Scientist
Ganesh Pandey, Engineer WR	Robert DuVall, Environmental Scientist
Amarjot Bindra, Engineer WR	John Robles, Environmental Scientist
Dainny Nguyen, Engineer WR	Russell Stein, Senior Environmental Scientist
Cosme Diaz, Supervising Engineer WR	Jerry Ripperda, Senior Environmental Scientist
Mike Driller, Senior Engineer WR	Derrick Adachi, Senior Environmental Scientist
Jasmine Doan, Engineer WR	Janis Offermann, Senior Environmental Planner

John Meininger, Engineer Mechanical
Robert Moore, Engineer Electrical
Brent Lamkin, Engineering Geologist
Frank Dubar, Retired Annuitant
McDonald, Chief Contracts Section

Laura Patterson, Environmental Scientist
Mike Bradbury, Staff Environmental Scientist
James Gleim, Environmental Scientist
Beth Hedrickson, Environmental Scientist
Harry Spanglet, Environmental Scientist
Chuck Vogelsang, Senior Env. Scientist

Operation Studies Team
Sushil Arora, Chief, Hydrology & Operations
Dan Easton, Engineer WR
Amarjot Bindra, Engineer WR
Jeremy Arrich, Senior Engineer WR
Sean Sou, Supervising Engineer WR
Ryan Wilbur, Engineer WR
Mike Moncrief, Engineer WR
Ganesh Pandey, Engineer WR

Water Quality Investigations Team
Tara Smith, Chief, Delta Modeling Section
Parviz Nader-Tehrani, Senior Engineer WR
Robert DuVall, Environmental Scientist
Ganesh Pandey, Engineer WR
Michael Mierzwa, Engineer WR
Hari Rajbhandari, Senior Engineer WR
Richard S. Breuer, Senior Env. Specialist
Philip Wendt, Chief Water Quality
Dan Otis, Environmental Program Manager
Bob Suits, Senior Engineer WR

Economic Analyses Team
Ray Hoagland, Chief, Economic Analysis
Farhad Farnam, Research Program Specialist II
Jim Rich, Research Program Specialist
Richard Le, Retired Annuitant
Amarjot Bindra, Engineer WR
Leslie Pierce, Senior Environmental Scientist

Policy and Legal
Cathy Crothers, Legal Counsel

Consultants
URS Corporation   CH2M HILL   MBK Engineers   Saracino-Kirby-Snow   Flow Science Inc.

***Additional Technical Assistance Provided by**

U.S. Fish and Wildlife Service
Ryan Olah, Environmental

California Department of Fish and Game
Jim Starr, Senior Biologist
Laurie Briden, Senior Biologist
Julie Niceswanger, Biologist

Table of Contents

List of Tables

List of Figures

List of Plates

Chapter 1: GENERAL

1.1 Introduction

The CALFED Record of Decision (ROD) identified five surface water storage projects: Enlarged Shasta, Los Vaqueros, Sites Reservoir, 250 to 700 TAF of additional storage in the upper San Joaquin River watershed and In-Delta Storage. The purpose of new storage in the Delta is to increase operational flexibility for the Central Valley Project (CVP) and the State Water Project (SWP) and provide ecosystem benefits in the Delta. The ROD included an option to explore the lease or purchase of the Delta Wetlands (DW) Project, a private proposal by DW Properties or to initiate a new project, in the event that DW Project proves cost prohibitive or infeasible.

A joint reconnaissance level study by the U. S. Bureau of Reclamation (Reclamation) and California Department of Water Resources (DWR) for the DW Project and alternatives, completed in September 2000, concluded that the In-Delta Storage Project would meet the goals of operational flexibility and provide other beneficial uses in the Delta.

The participating CALFED agencies initiated a project study of the In-Delta Storage Project in January 2001. The project study included investigations related to operational flexibility, water quality, engineering, environmental, economic, and policy and legal evaluations. At present the In-Delta Storage project is being studied as a joint federal state project.

1.2 Project Descriptions

The In-Delta Storage project consists of developing Webb Tract and Bacons Island as reservoir islands. To mitigate the environmental impacts caused by the proposed project, Holland Tract and Bouldin Island will be developed as habitat islands. The locations of the project and habitat islands in the San Joaquin-Sacramento Island Delta are shown in Figure 1.1.

The In-Delta storage reservoir project is proposed to be operated as a joint Federal and State project. Under the planned operations scenario, the water into the reservoirs will be diverted during the winter months. The reservoir water will be released back to the Delta channels during the summer months when the demand is high and flow is low. The diversion and release in and out of the reservoirs will be carried out from four integrated facilities. The project island soil is predominantly peat soil. Over the storage period and due to mass exchange and bio-productivity there is a high potential for the increase in the dissolved organic carbon (DOC) of the stored water. Because of the proximity of the project to the urban intakes, the DOC at the urban intakes could be impacted due to the reservoir releases. Thus determination of the DOC level of the stored water and the impacts of the released water to the DOC at the urban intakes and Delta channels is a key requirement for the viability of the project. This report summarizes the findings of series of numerical and experimental studies intended to assess the impacts of In-Delta storage project in the DOC, DO and temperature of the Delta water supply systems under varied operation rules.

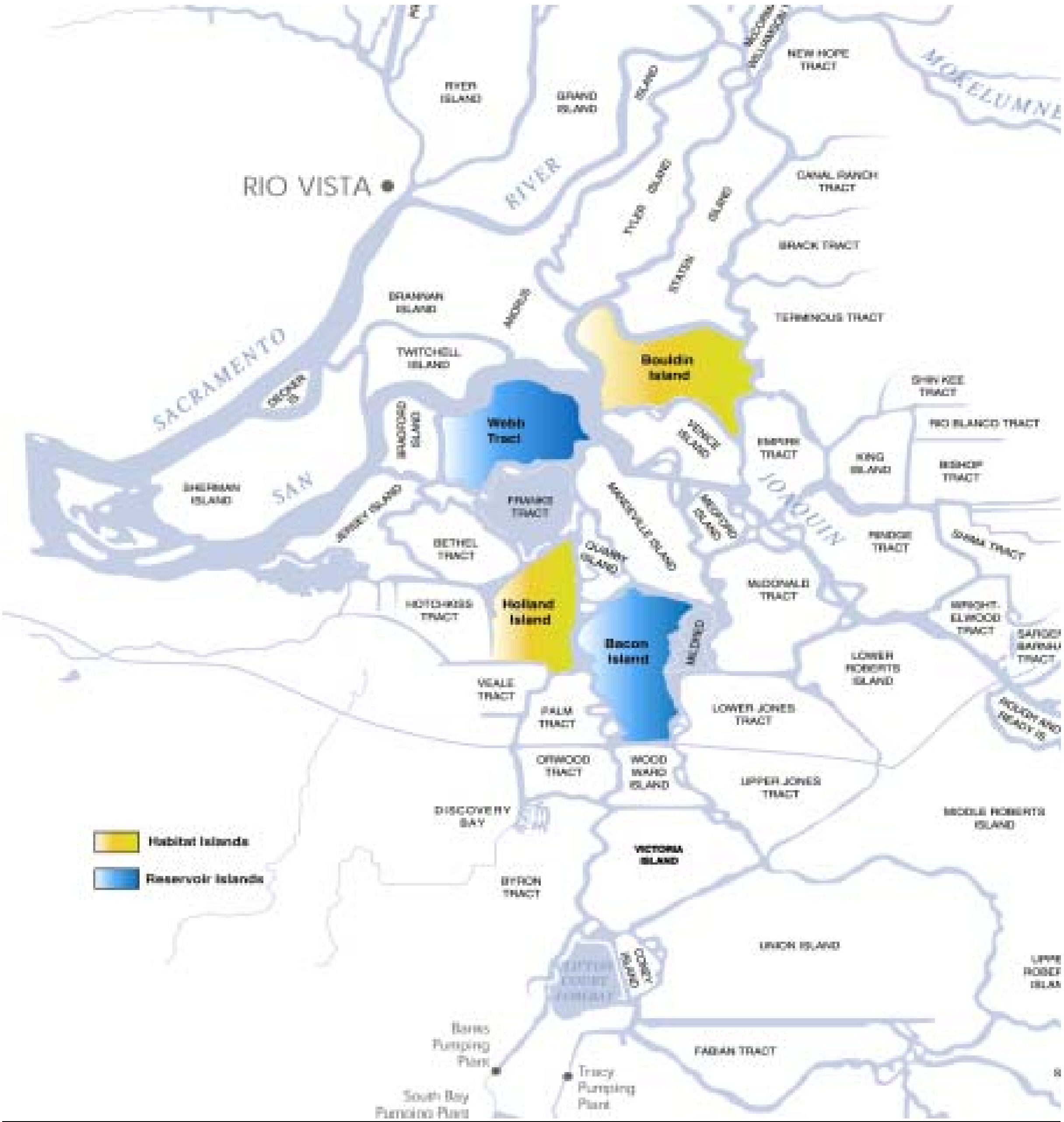


Figure 1.1: Proposed Habitat and Reservoir Islands for In-Delta Storage Project

1.3 Water Quality Requirements

The water quality requirements for the DW Project are set forth in the SWRCB Decision 1643 (D1643) and the Water Quality management Plan (WQMP) and the California Urban Water Agencies (CUWA). Most of the operations rules outlined in D1643 and WQMP were intended for the In-Delta storage project as a private holding by the Delta Wetlands Properties. These operating rules might change as the project is intended to be operated as a joint federal and state project.

1.3.1 General Requirements

Discharges of water from the project shall not cause: (1) an exceedance of any applicable water quality objective in a water quality control plan adopted by the SWRCB or by the RWQCB; (2) any recipient water treatment plant to exceed the maximum contaminant levels for disinfection byproducts as set forth by EPA in Title 40, Section 141.12 & 141.30. The regulated classes of disinfection byproducts are trihalomethanes, haloacetic acids, chlorite, and bromate (SWRCB, condition 14.a.). For the purpose of determining that the Project has caused an exceedance of one or more of the operational screen criteria, an uncertainty of ±5% of the screening criteria will be assumed.

1.3.2 Long-Term Requirement

The Project is required to mitigate 150% of the net increase in TOC and salt (i.e. TDS, bromide and chloride) loading greater than 5% in the urban diversions due to Project operations.

1.3.3 Total Organic Carbon

The project operation shall not cause or contribute to total organic carbon (TOC) concentrations that will violate either criteria:

- Increase in TOC concentration at a SWP, CVP, CCWD pumping plant, or at a receiving water treatment plant that will cause the limit of 4.0 mg/L (14-day average) to be exceeded;
- Incremental increase in TOC concentration at a SWP, CVP, or CCWD pumping plant of greater than 1.0 mg/L (14-day average) (SWRCB, condition 14.b.).

In this study DOC was used as a surrogate for TOC.

1.3.4 Chloride

Chloride concentration shall not:

- Increase more than 10 mg/L chloride concentration at any of CCWD’s intakes
- Cause any increase in salinity of more than 10 mg/L chloride (14-day running average salinity) at any urban intake in the Delta
- Cause or contribute to any salinity increase at one or more urban intake in the Delta if the intake is exceeding 90% of an adopted salinity standard (Rock Slough chlorine standard defined in SWRCB Decision 1641) (SWRCB, condition 14.c.)

1.3.5 Disinfection Byproducts

The Project operations will be curtailed, rescheduled, or constrained to prevent impacts on drinking water quality at any water treatment plant receiving water from the Delta based on the following WQMP screening criteria:

- Modeled or predicted Total Trihalomethanes (TTHM) concentrations in drinking water in excess of 64 µg/L, as calculated in the raw water of an urban intake in the Delta or at the outlet of a water treatment plant.

- Modeled or predicted bromate concentrations in drinking water in excess of 8 µg/L, as calculated in the raw water of an urban intake in the Delta or at the outlet of a water treatment plant.

1.3.6 Dissolved Oxygen (DO)

No discharge of stored would be allowed water if the DO of stored water:

- Is less than 6.0 mg/L, or
- Causes the level of DO in the adjacent Delta channel to be depressed to less than 5.0 mg/L, or
- Depresses the DO in the San Joaquin River between Turner Cut and Stockton to less than 6.0 mg/L September through November. (SWRCB, condition 19.a.)

1.3.7 Temperature

No discharge of stored water would be allowed if:

- The temperature differential between the discharge water and receiving water is greater than 20º F,
- It will increase the temperature of channel water by more than:
  4º F when the temperature of channel water ranges from 55º F to 66º F
  2º F when the temperature of channel water ranges from 66º F to 77º F
  1º F when the temperature of channel water is 77º F or higher (SWRCB, condition 20.b.)

1.4 Scope of Work

To address the water quality issues of the In-Delta storage reservoir project at the urban intakes and Delta channels, one field experiment and three numerical studies were planned. The field study is aimed at determining the growth rate of DOC in the stored water as a result of mass exchange and bio productivity activities. The numerical studies were intended to examine the DOC, DO and temperature in the Delta water ways and urban intakes due to the releases from the project reservoirs.

1.4.1 Modeling Studies

The water quality modeling studies were conducted with the Department's Delta Simulation Model (DSM2). The objectives of the modeling studies were to assess the feasibility of the In-Delta storage reservoir project operations under D1643 and WQMP. The modeling study had following objectives.

- Revise the organic carbon growth algorithm in DSM2 to better address carbon loading from peat soils and biological productivity.
- Revise estimates for likely organic carbon concentrations in storage water in comparison to the base No Action conditions.
- Create dispersion rules for CALSIM II recirculation studies and check final reservoir DOC at the urban intakes for the final CALSIM II run.

- Compare water quality constituents under base No Action conditions with In-Delta Storage Project operations under D1643 and WQMP.
- Provide input to Reservoir Stratification studies.

1.4.2 Water Quality Field Investigations

The following work was done as part of the field investigations to estimate the organic carbon loading from peat soils and biological productivity on the reservoir islands.

- Review of the literature on organic carbon loading in the Delta for information that may be applicable to in-Delta storage.
- Evaluate likely DOC concentrations and loads expected in storage water using mesocosms or physical models of the proposed reservoir islands.
- Integrate results from filed studies with mathematical models of the proposed reservoir islands, the Delta and the State Water project.

1.4.3 Temperature and Stratification Modeling

The DYRSEM model was used to study the stratification of the reservoir and to predict the temperature differentials between the reservoir islands and the receiving channels. The DYRSEM model study was done by the Flow Science Inc., and the study period covered three representative years (dry, normal and wet) for different project operation scenarios. Particularly, the study focused on the following issues.

- Develop meteorological data sets for the reservoir islands.
- Determine if the reservoir islands will stratify using the one-dimensional DYRESM model.
- Quantify likely water temperatures for the reservoir islands and discuss potential changes in channel temperature resulting from reservoir discharge.

A report by the Flow Science Inc. outlining the detailed methodology, assumptions and results of the DYRSEM model studies of the In-Delta storage islands is given in Appendix C.

1.5 Conclusions and Recommendations

1.5.1 Conclusion

Based upon the field investigations and modeling studies, key findings can be summarized as follows:

DSM2 Modeling Findings:

- The DOC concentration in the project island is both a function of the mixing associated with diversions to the islands, the production of organic carbon mass from algae and wetlands plants, and the addition of organic carbon mass due to leaching and microbial decay of the peat soils. The recirculation operation mitigates the effect of DOC growth within the island.
- The 14-day average DOC is within the WQMP 14-day standard. However, some violations were observed on the difference between the alternative and base operations.

- The increase in DOC due to the recirculation operation is less than 1 mg/L 93% of the time.

DO and Temperature Modeling Findings:

- DSM2 modeling indicates that for the Alt-1 operations DO conditions will not be violated. It was assumed that the island DO levels would not fall below 6 mg/l as required. A few days violations could occur for the temperatures that are higher than 77 degrees. The model results were based on daily averaged values.
- Water quality data needed for boundary conditions for the planning study were based on extrapolation of available data, when historical data were not available.
- Model simulation did not indicate that differences in water temperature between the island and the channel would exceed 20 degrees.

Water Quality Field Investigations Findings:

- Carbon loading in the reservoir islands is likely to be primarily from a single source, peat soil, and can be modeled in using an aerial rate of approximately 0.47 mg $C/m^2/d$. This rate may be lower with circulation. Experimental observations to date indicate rates as low as 0.25 mg $C/m^2/d$
- Biological productivity from Egeria densa, while dramatically different in terms of biomass in the deep vs. shallow mesocosms, did not result in dramatic or obvious differences in dissolved organic carbon concentrations or thrihalomethane formation potentials between the two sets of mesocosms.

DYRESM Modeling of Temperature and Stratification Findings:

- Thermal stratification is more likely to occur at In-Delta storage reservoirs at lower wind speeds (about 2 m/s). However, for all year (dry, normal and wet) types, stratification in the reservoirs was weak and short lived.
- Summertime reservoir water temperature would generally remain in the range of 77 to 86^0 F.

1.5.2 Recommendations

DSM2 Modeling: The following recommendations were made to improve the results of the DSM2 model studies.

- Permanent barriers were included in all four simulations, however, the operation (i.e. timing) of the barriers were based on the different operations. A schedule and description of what the operation of the barriers for each scenario is critical to understanding the flow patterns in the South Delta and can have an impact on the fate of particles released from the project islands.
- Implement and refine CALSIM2 water quality operating rules through iteration with DSM2.
- DSM2-PTM was run for Alt 1 in order to improve the CALSIM II DOC constraints. The fate of particles released from both islands was used along with export / inflow ratio information taken from CALSIM to develop relationships estimating how much of the organic carbon released from either island made it to Banks and Tracy pumping plants. Reiteration of the CALSIM and DSM2 runs will improve the results.

Water Quality Field Investigations: Additional studies, at different spatial and temporal scales are needed to better understand and predict complex and interacting ecological processes like phytoplankton and dissolved oxygen dynamics. Additional experiments are needed to determine how management practices, such as tilling the fields prior to flooding or exchanging water with circulation flows, affect water quality.

Modeling of Temperature and Stratification: Weather stations that measure wind speed and direction are needed at the reservoir islands. In the absence of site specific wind monitoring data, it is not possible to know exactly the wind speeds at the proposed reservoir locations. For this reason, a range of wind speeds has been evaluated, and the simulated reservoir water temperature and stratification have been predicted for the full range of potential wind speeds. It is anticipated that actual field wind speeds within the Delta will fall somewhere between the low and high values used in the modeling. As expected, reservoir water temperatures and stratification conditions are highly sensitive to wind speed. Many of the differences between measured wind speed at various stations in the Delta are likely caused by local differences in topography (e.g., there may be a "sheltering effect" at the Brentwood site).

Chapter 2: WATER QUALITY MODELING STUDIES

2.1 Introduction

A series of four DSM2 daily planning studies were run in HYDRO, QUAL, and PTM based on the proposed operations for the In-Delta Storage (IDS) project islands based on the CALSIM II Daily Operations Model (DOM). Since only some of the CALSIM II scenarios were run using DSM2, new scenarios names consistent with the DSM2 planning configuration were used instead of the CALSIM II scenario names. All scenarios reflect Delta operations in accordance with SWRCB Decision 1641. The first scenario is a "base case" without In-Delta Storage Program facilities and the remaining scenarios differ in terms of specified operation rules and constraints. All study scenarios assume Delta hydrology and operations as provided by CALSIM II model simulations. A basic description of the DSM2 / CALSIM II scenarios is given in Table 2.1. Detailed assumptions, operations rules and constrains of each alternative scenarios are described in Operations Study Report.

Table 2.1: DSM2/CALSIM II Operation Scenarios

DSM2 Study	CALSIM II Study	Description
Scenario1(Base)	Study 1	No IDS project islands
Scenario 2(Alt 1)	Study 3a	IDS project islands w/ no DOC constraints
Scenario 3(Alt 2)	Study 3b	IDS project islands w/ DOC constraints
Scenario 4(Alt 3)	Study 4	IDS project islands w/ DOC constraints & island recirculation

HYDRO and QUAL were run for all four scenarios. The DOC concentration on each island in Alt 1, along with PTM based regressions of the percentage of particles from both islands that travel to the State Water Project (SWP) and Central Valley Project (CVP) during project island release periods were used to improve the CALSIM II DOC constraints. PTM was run only for Alt 1.

2.2 Methodology

2.2.1 Tools

The water quality modeling studies were conducted with the Department's Delta Simulation Model (DSM2). The performance of DSM2 model in simulating flow was examined by the Bay-Delta modeling forum through independent peer review process. For a variety of geometry, initial and boundary conditions, the DSM2 model performed well and conserved both mass and momentum. Details of the review process and model performances can be found at http://www.cwemf.org/1-DReview/default.htm. The DSM2 was calibrated and validated for flow, stage and electrical conductivity (EC) in collaboration with the DSM2 Interagency Ecological Program Project Work Team. The model was also successfully validated for the transport of dissolved organic carbon (DWR, 2001). The validation plots for four locations which are close to the project site are given in Appendix B. Detailed information on recent calibration, validation and model accuracy can be found at http://modeling.water.ca.gov/delta/index.html.

For all three alternatives, the DSM2 simulations covered the 16-year period October 1, 1975 through September 30, 1991. Daily varying Delta hydrology and operations for the study period were provided by CALSIM II as input to the DSM2 simulation. CALSIM II rules were developed to approximately meet the water quality screening criteria spelled out in the D1641, D1643 and other applicable guidelines. Several new features were developed for DSM2 in support of the In-Delta Storage water quality evaluations. The key enhancements were (1) modified hydrodynamics, hydrology and operations input and (2) a dynamic flooded island algorithm. These new features are described briefly in the following paragraphs.

DSM2 planning studies typically utilize CALSIM II hydrology and operations as input. In the past, CALSIM II has provided this input on a monthly time step. As part of the In-Delta Storage evaluations, CALSIM II was enhanced to simulate Delta operations on a daily time step. Several complex modifications were made to the DSM2 planning study setup to ensure compatibility with daily information from CALSIM II. The DSM2 planning study setup was also modified to accommodate a historical based (non-repeating) tide. Previous DSM2 planning studies utilized a 25-hour repeating tide to represent the model's downstream boundary at Martinez. While such an approach is computationally advantageous when used in conjunction with a monthly varying hydrology, it does not allow for the evaluation of spring-neap effects. A 16-year historical based planning tide was developed to reflect approximate historical conditions for every computational time step (i.e. 15 minutes) of the DSM2 simulation period (DWR, 2001). Using historical based tides, DSM2 provides more meaningful hydrodynamic and water quality responses to daily changing hydrology and operations and incorporates spring-neap tidal variations.

Field experiments were continued to investigate the DOC growth in the flooded island. The experimental data were used to modify the DOC growth algorithm for the flooded island. This algorithm was coded and incorporated in DSM2 to provide a dynamic simulation of water quality changes in the Project reservoirs.

2.2.2 Evaluation Criteria

The water quality modeling studies utilized the D1643 and WQMP as the basis for developing evaluation criteria. The WQMP identifies several urban intakes as having the potential to be negatively impacted by the In-Delta Storage reservoir project. For these studies, model results were evaluated at the following urban intakes: Old River at Rock Slough, Old River at the Los Vaqueros Reservoir intake, Banks Pumping Plant and Tracy Pumping Plant.

The WQMP outlines several screening criteria, including constraints on total organic carbon (TOC), chloride, total trihalomethanes (TTHMs), and bromate. Water quality values are generally specified as 14-day averages in the WQMP. The key evaluation criteria utilized in this study were as follows:

- The Project cannot cause an increase in chloride of more than 10 mg/l, and it cannot cause or contribute to any salinity increases at urban intakes exceeding 90% of adopted salinity standards.
- The Project cannot cause an increase in TOC of more than 1.0 mg/l, and it cannot cause TOC to exceed 4.0 mg/l at urban intakes.

- The Project cannot cause or contribute to TTHM concentrations in excess of 64 µg/l, as calculated in raw water of urban intakes.
- The Project cannot cause or contribute to bromate concentrations in excess of 8 µg/l, as calculated in raw water of urban intakes.
- The Project cannot cause a net long-term increase in TOC and salt loading greater than 5% in the urban diversions due to Project operations. For the In-Delta Storage water quality evaluation, long-term impacts were calculated as flow-weighted 3-year running averages.

2.2.3 Simulated Constituents

DSM2 model simulations were conducted for DOC and it was modeled as conservative constituent. DSM2 model has also been used to simulate DO, which is a non-conservative constituent and has been described in section 4 of this report. The CALSIM II study shows that EC is not a problem for the revised operations and therefore this constituent was not simulated in the present study. The behavior of other conservative constituents (TOC, BROMIDE, Chloride, UVA and TTHM) could be derived from EC and DOC using established statistical relationships. For example DOC was used as a surrogate for TOC and EC was used as a surrogate for chloride and bromide in the model simulations. Statistical relationship between ultraviolet absorbance at 254 nm (UVA) and DOC at the urban intakes was developed using results from previous studies. Simulated DOC and bromide (converted from EC) values, computed UVA values, and approximate water temperatures were used to compute TTHM concentrations. The relationship between the DOC, EC and other constituents are positive. This means when the DOC or EC increases so does the TTHM and UVA and vice versa. Thus, any improvement / decrease in the DOC at any location will have a corresponding improvement / decrease of other constituents.

The DSM2 results based upon the 2002 studies suggest that the In-Delta storage reservoir has significant impact on the DOC. The project's impacts on other constituents (that is, EC, UVA, Chloride, Bromide, UVA, and TTHM) were minimal (Appendix A). Using the latest experimental data, the DOC growth algorithm at the flooded island was modified and new operating rules. DSM2 modeling studies were conducted with DOC only. As will be shown in the subsequent sections, under the new operating rule the DOC in the channel as well as urban intakes improves substantially. Because of the positive relationships between DOC and other constituents, lowering of the DOC will imply lowering of the other constituents. For the remaining constituent, results from the 2002 studies were taken and are summarized in Appendix A. Nevertheless, the revised project operation rules are expected to have favorable impacts in these constituents as well.

2.3 Key Assumptions

2.3.1 Project Configuration

The configurations of In-Delta Storage reservoir island intake and discharge locations, as modeled by DSM2, are shown in Figures 2-1 and 2-2.

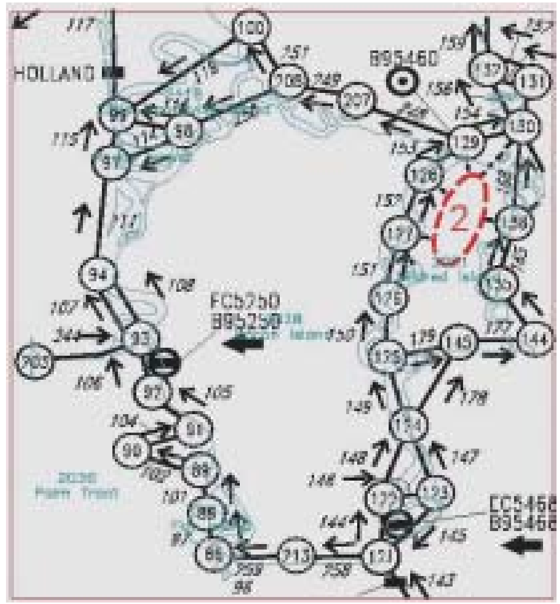


Figure 2-1: DSM2 Representation of Bacon Island

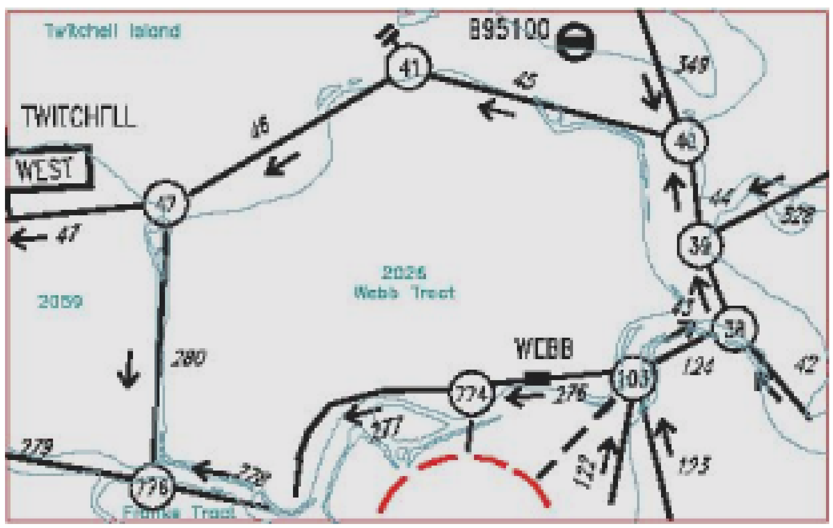


Figure 2-2: DSM2 Representation of Webb Tract

In the base case scenario, the project islands are treated as agricultural islands. In the remaining alternatives, the project islands were treated similar to other DSM2 reservoirs. DSM2 treats reservoirs as tanks with constant surface areas and variable depths. The storage area, surface area, and diversion / release siphons for each island were based on the current ISI-IDS island designs. The configuration of the project islands as modeled by DSM2 is shown Table 2.2.

Table 2.2: In-Delta Storage Project Island Configuration

Island	Storage Capacity (TAF)	Surface Area (acres)	Siphon #1 DSM2 Node	Siphon #2 DSM2 Node
Bacon Island	120	5,450	128	213
Webb Tract	118	5,370	40	103

The surface area was chosen such that when full, each island would have a maximum depth of approximately 20 ft. Volume of a reservoir in DSM2 is the product of the reservoir's surface area and its current stage level. In order to prevent drying up of the island reservoirs an addition 2 ft of water was assumed to be present on both islands at the beginning of the simulation. This water was a combination of dead storage and initial storage.

2.3.2 Project Island Hydrodynamics

For all three alternative simulations, CALSIM II determined the daily diversions to and releases from the project islands, in addition to optimizing the exports at both the Banks (SWP) and Tracy (CVP) Pumping Plants. Diversions to and releases from the two project islands were controlled in DSM2-HYDRO by "object-to-object" transfers. In other words, there was no direct physical connection between the project islands and neighboring channels. Instead, water was pumped via two siphons for each island. Diversions onto an island were assumed to be uniformly mixed with the water already present on the island. The concentration of DOC released from an island was assumed to be the same concentration of the island, thus releases had no impact on the island's DOC concentration. Hence significant changes in the DOC concentration on each island coincide with diversions to the islands.

2.3.2.1 Siphons

Two different siphons were used to divert and release water. For the first two alternatives, the flows associated with both siphons were identical. For Alt 3, water was circulated to and from the islands to help reduce the island DOC concentration. The northern most intake on each island was used to divert lower DOC water from nearby channels, while the southern most siphon released the higher DOC water from the islands.

2.3.2.2 Evaporation Losses

In addition to diversions and releases associated with increasing SWP and CVP exports, evaporation losses and surplus agricultural diversions were provided by CALSIM II. Under the current IDS proposal, both islands will retain their agricultural diversion water rights, and this water was used to make up for the evaporation losses. Because the evaporation losses associated with storage did not coincide with periods that the project could divert the make-up agricultural water, thus there were minor fluctuations in the stage.

2.3.2.3 Seepage

Because the elevation of most Delta islands is lower than the low tide water surface in the channels that surround the islands, seepage usually occurs from the channels onto the islands.

However, when water is stored on the IDS project islands, the gradient of ground water flow between the neighboring channels and islands will at times be reversed. Water from the island reservoirs will move to the channels, carrying with it organic carbon from the island peat soils.

To prevent this reverse seepage, the IDS project will use interceptor wells to collect water moving from the islands to the channels. After collecting the water, the wells will return the seepage flows back to the island.

Although there is no net change in storage due to seepage when using wells to return water lost due to seepage, the collected water will have a high concentration of organic carbon. In order to account for the addition of this organic carbon to the island reservoirs, seepage losses and returns were calculated for both Bacon Island and Webb Tract. Seepage losses were removed directly from the reservoir, while the return flows from the interceptor wells were added back to the reservoirs. There is no interaction of the seepage water with the neighboring channels.

In the field, seepage losses will occur only at times when the stage in the island reservoirs is higher than the stage of the surround channels; however, it was necessary to assume a fixed water level for each island to trigger when seepage would occur.[1] Seepage flows resulted only when the stage results from CALSIM II were greater than or equal to -1.0 ft. In situations where the project islands were partially full, this reverse seepage would not occur.

Though the losses and returns for each island were identical in magnitude, 9.80 cfs for Bacon Island and 1.96 cfs for Webb Tract, the water quality associated with the flows is different. Since the seepage losses are treated as a sink, there is no need to worry about the quality associated with this flow; however, the water returned to the islands assumed to have a fixed DOC concentration of 20 mg/L.

2.3.2.4 Stage

The DSM2 stage for all three alternatives on both islands is shown and summarized Table 2.3. When the stage is around -20 ft, the islands are empty. When the stage is above 0 ft, the islands are near capacity. The stage results also indicate periods when the islands are partially full. Variations in the island stages for all alternatives are shown in Figures 2.3 and 2.4

Table 2.3: Maximum Daily Averaged Stage (ft) of Island Reservoirs

	Alt 1			Alt 2			Alt 3		
Island	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min
Bacon Island	1.4	-12.5	-19.5	1.9	-4.3	-19.0	1.9	-5.3	-19.0
Webb Tract	-1.5	-14.5	-20.0	-1.5	-8.6	-20.0	-1.5	-9.2	-20.0

[1] The alternative to using a fixed CALSIM II stage trigger would have been to run HYDRO as an iterative process. Since the volume of storage is not affected by seepage, no seepage flows would have been included in the first HYDRO simulation. The stage results from the first HYDRO simulation would be used to develop seepage estimates based on the elevation differential between an island and its surrounding channels for a second HYDRO simulation. Time constraints prevented this technique from being used.

2.3.3 Delta Inflow Water Quality Boundary Conditions

Time series of Delta inflow DOC concentrations were developed from available flow and water quality grab sample data to provide boundary conditions for DSM2. Field observations suggest that organic concentrations can vary considerably during a month at the model boundary locations, particularly during high precipitation runoff periods in winter. But due to a lack of continuous DOC monitoring, a time interval of one month was selected for the boundary condition time series. Delta inflow DOC boundary conditions for the 16-year simulation period are shown in Figure 2-5.

2.3.4 Project Storage and Habitat Islands

Project reservoir evaporation and diversion/release flows were provided by the CALSIM II operations study. Reservoir seepage return flows were based upon the recent studies conducted by the URS Corporation (URS 2003). Habitat island diversion and return flows, which are relatively small, were assumed in accordance with the Delta Wetlands Environmental Impact Report (JSA, 2000). To ensure consistency with the CALSIM II operations studies, Delta-wide consumptive use (based upon a 2030 level of development) was held constant between the Base scenario and remaining alternatives.

With respect to water quality, In-Delta storage reservoirs were modeled as fully mixed, i.e. diversion volumes fully mix with storage volumes at each time step of the model simulation. As a simplifying assumption, reservoir water quality was not updated to reflect the concentrating effects of evaporation and the diluting effects of precipitation. This more accurate modeling approach would have required extensive model enhancements and would not have changed the model results significantly.

Habitat island water quality was not modeled dynamically, since the small winter return flow volumes were expected to have little impact on overall simulation results. Instead, fixed concentrations based on field observations (Jung, 2001) were assumed to represent typical winter return water quality. Values of 50 mg/l DOC and 750 umhos/cm EC were assumed for Bouldin Island and 40 mg/l DOC and 1100 umhos/cm EC were assumed for Holland Tract.

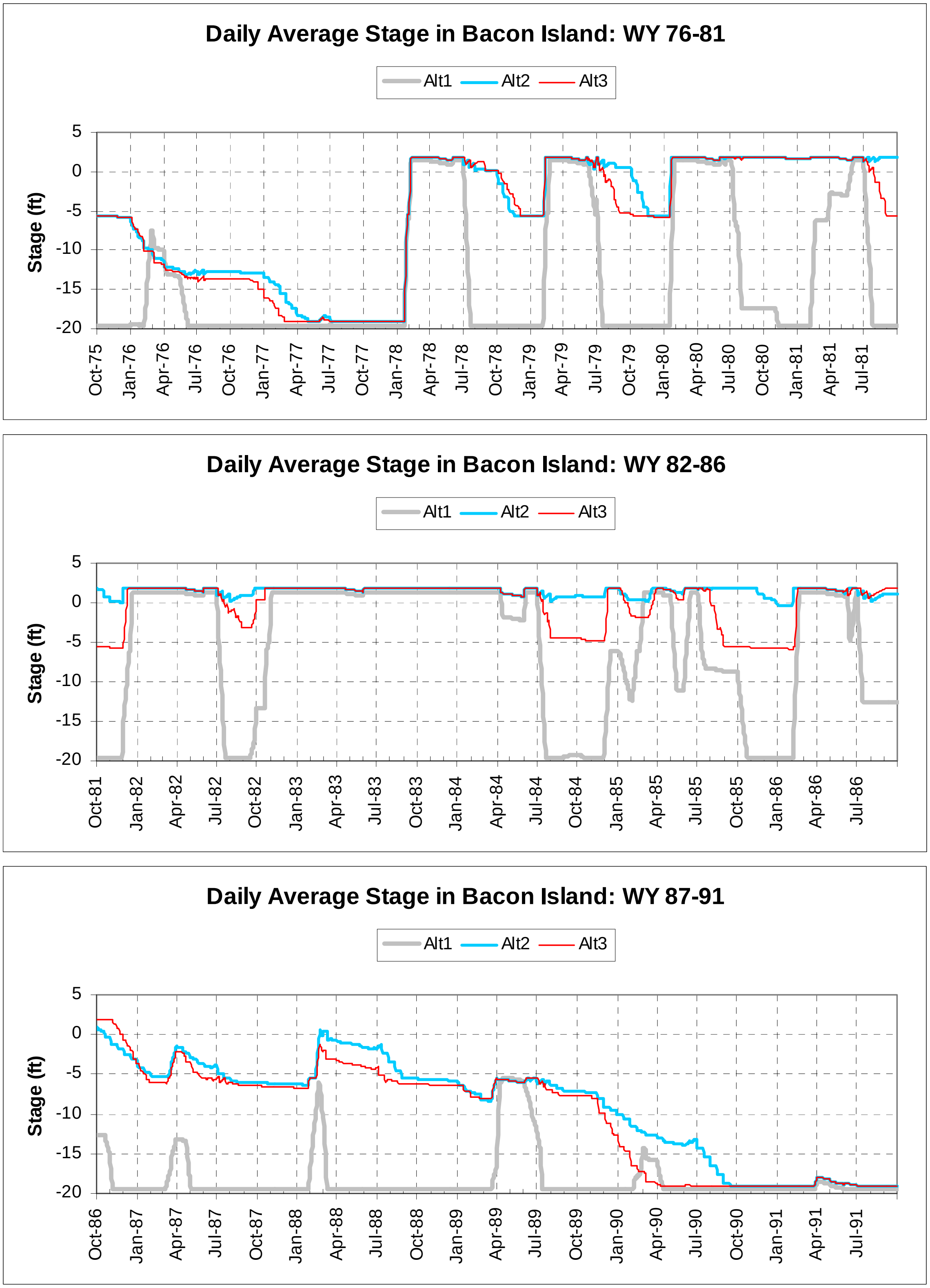


Figure 2.3: Daily Average Stage in Bacon Island

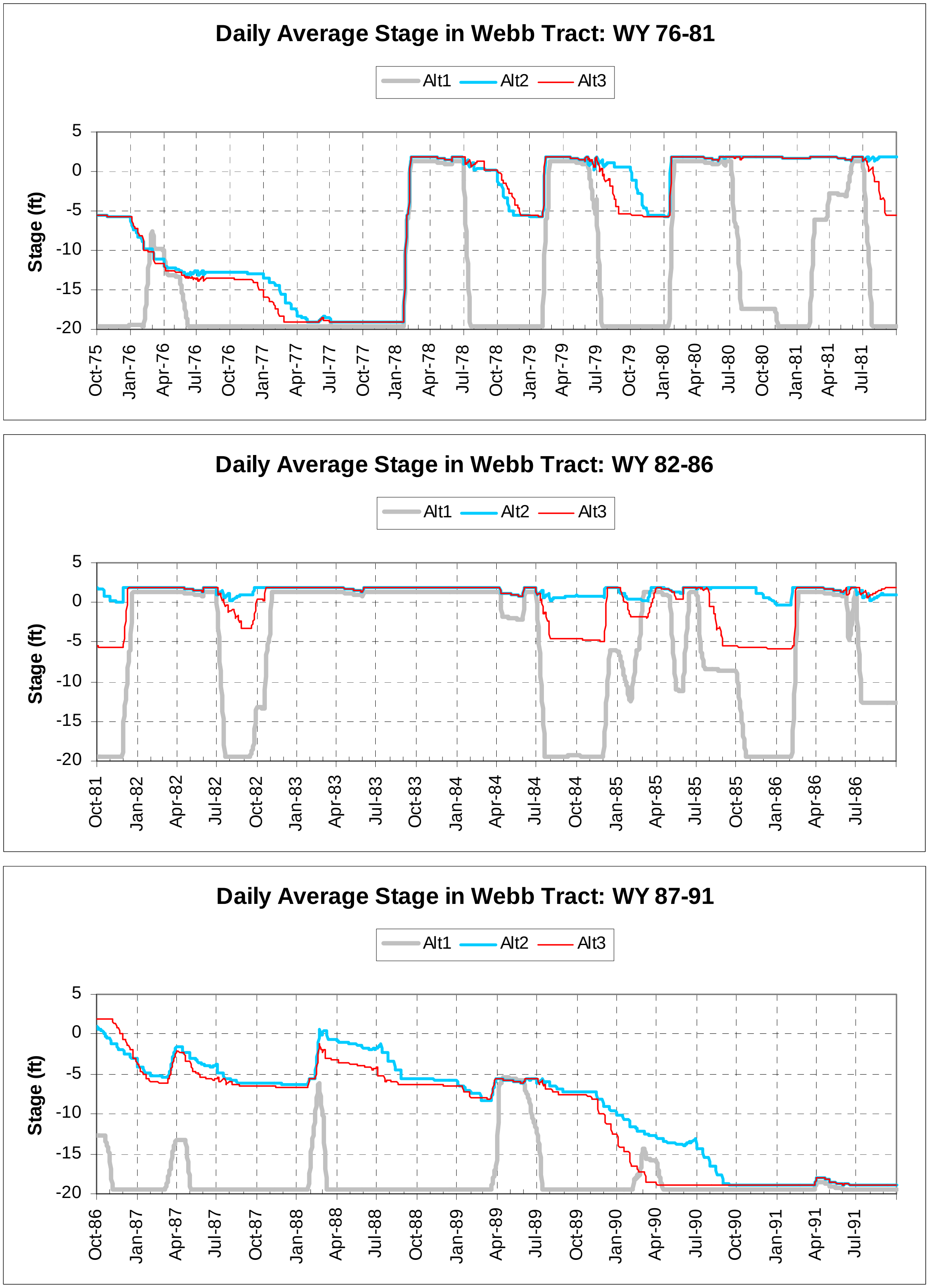


Figure 2.4: Daily Average Stage in Webb Tract

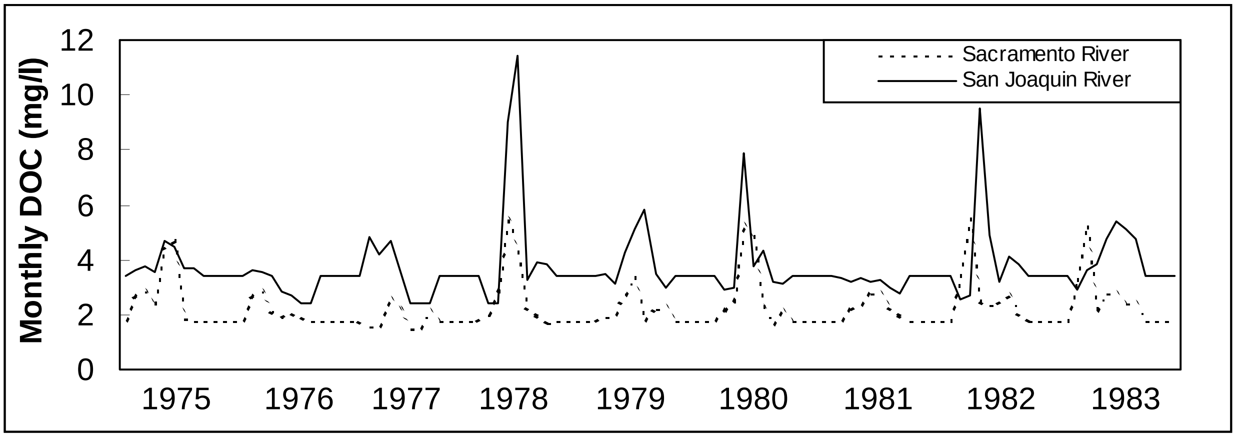


Figure 2-5a: Delta Inflow DOC Boundary Conditions: 1975-1983

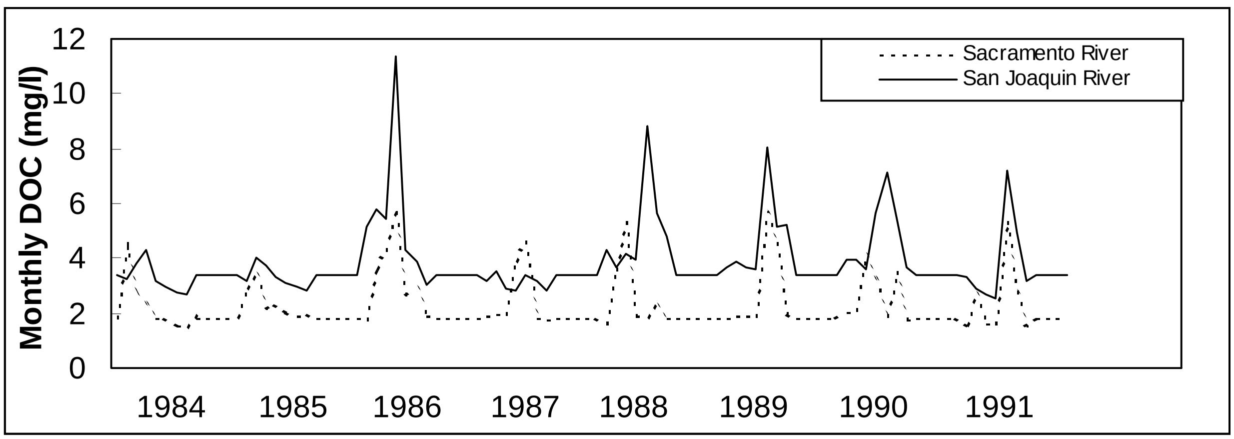


Figure 2-5b: Delta Inflow DOC Boundary Conditions: 1984-1991

2.3.5 Delta Agricultural Islands

Delta island diversion and return flow volumes were not measured in the field but were estimated with the Department's Delta Island Consumptive Use (DICU) model (DWR, 1995a). The DICU model computes diversion and return volumes on a monthly time step and allows for annual variability in response to changes in Delta land use, precipitation and pan evaporation. Return salinity water quality estimates are documented elsewhere (DWR, 1995b). Return organic water quality estimates were based on MWQI measurements. Due to a lack of comprehensive monitoring of over 200 agricultural drains in the Delta, return organic water quality data were compiled using a simplified aggregation technique (Jung and Associates, 2000). The Delta was segregated into three DOC sub-regions: high-, mid- and low-DOC. For each sub-region, representative monthly average DOC and UVA values were developed. UVA values were assumed as a linear function of DOC concentrations in all Delta island return flows. DOC and UVA values were assumed to vary by month but not by year. Monthly DOC concentrations from the three sub-regions are displayed in Figure 2-6.

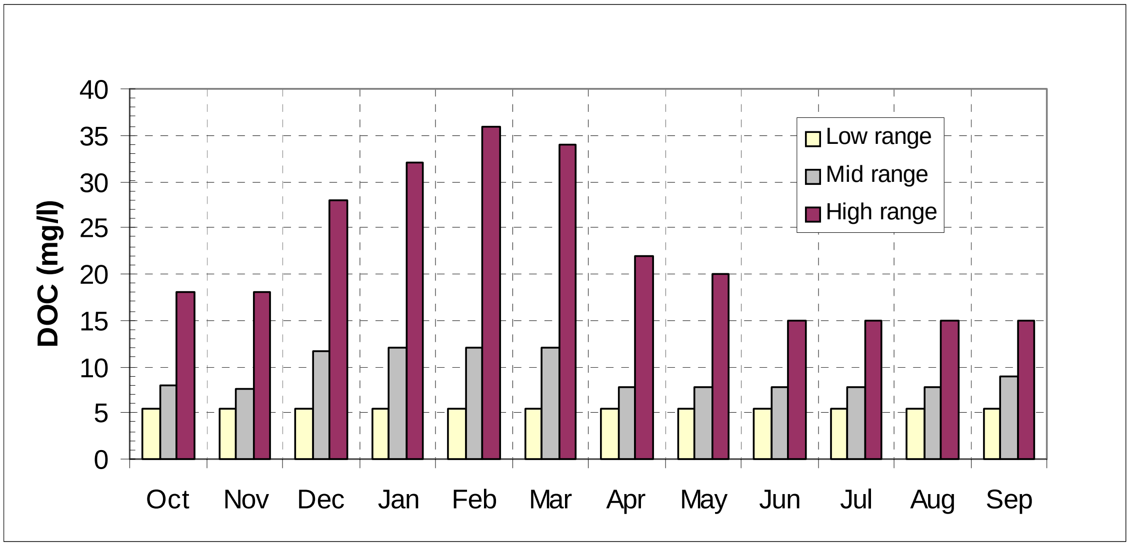


Figure 2-6: Monthly Agricultural Return Flow DOC Concentrations

2.4 Results

2.4.1 Project Island DOC

Located in the Central Delta, both Bacon Island and Webb Tract have a significant impact on the intake of organic carbon at Banks Pumping Plant (SWP), Tracy Pumping Plant (CVP), Los Vaqueros Reservoir Intake, and the Contra Costa Canal Pumping Plant. These islands' peat soils are a significant source of the high DOC concentrations of the agricultural returns, which can exceed 30 mg/L (Jung, 2000). Furthermore, both islands are close enough to four of the major urban water supply intakes that releases of the high DOC water from the islands has been shown to have significant impacts on the DOC at these intake locations (Mierzwa, 2002).

As shown in the stage plots above, water was typically diverted to the islands during the late winter and early spring. Unfortunately, the DOC concentrations associated with the inflows to the Delta are also highest at this time. Because DOC concentration cannot decrease with time, the DOC of the typical summer time releases is already higher than the water already in the Delta channels.

The concentration inside either island is both a function of the mixing associated with diversions to the islands, the production of organic carbon mass from algae and wetlands plants, and the addition of organic carbon mass due to leaching and microbial decay of the peat soils. The increase in DOC concentration associated with storing water on the peat soil islands is accounted for in QUAL by a DOC growth algorithm (Mierzwa *et al.*, 2003). These relationships are based on field studies conducted by DuVall (2003) that took into account both the increases in organic carbon mass due to decay and leaching as well as the increases due to production of new organic carbon from algae and wetland plants. The DOC growth rates (gC/m^2/day) used for all three alternatives are shown in Table 2.4.

Table 2.4: Project Island DOC Growth Rates (gC/m^2/day)

Island	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Bacon Island	0.47	0.0	0.0	0.0	0.0	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Webb Tract	0.47	0.0	0.0	0.0	0.0	0.47	0.47	0.47	0.47	0.47	0.47	0.47

As mentioned above, in order to prevent both islands from running dry, 2 ft of depth was assumed to represent both the initial stage and dead pool in each island reservoir. Mierzwa *et al.* (2003) described problems in QUAL when the reservoir depth approaches zero while new carbon mass is still being added to the system. In order to avoid this numerical instability and account for the 2 ft dead pool, the minimum reservoir depth limit for DOC growth was set to 4 ft. In other words, DOC mass would be added to either island only when (1) the stage in the island is greater than -18.0 ft, and (2) the DOC growth rate is greater than 0.0 gC/m^2/day.

The variations of the project island DOC are summarized in Table 2.5. Monthly variations for all alternatives are given in Figures 2.7 and 2.8. The model study results show that the planned recirculation operation, that is Alt. 3, reduces the maximum and average DOC in the project islands.

Table 2.5: Maximum Daily Averaged DOC (mg/L) in Island Reservoirs

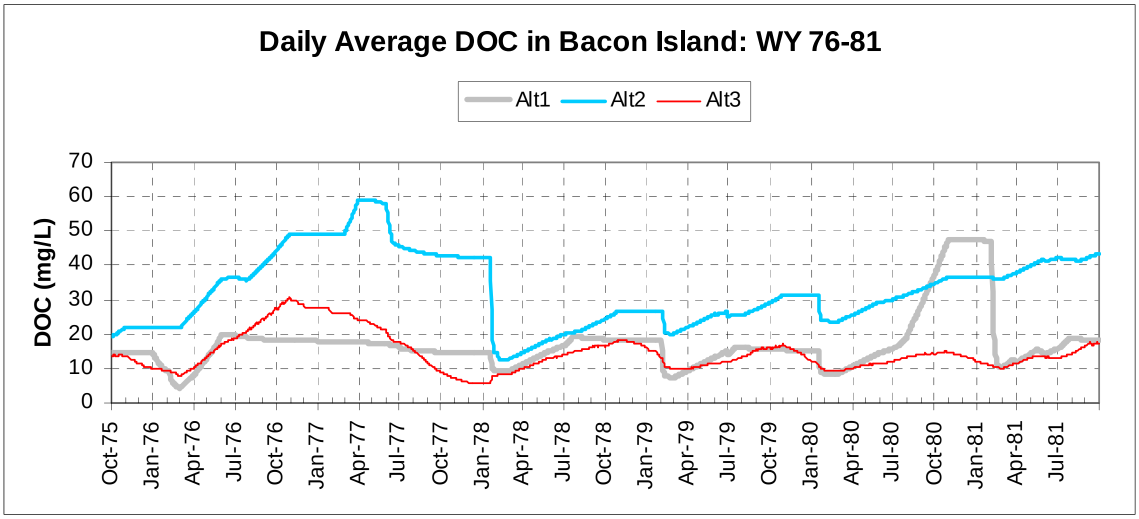
	Alt 1			Alt 2			Alt 3		
Island	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min
Bacon Island	47.8	16.3	4.4	82.2	49.6	12.7	31.1	14.0	4.6
Webb Tract	33.8	15.6	4.2	74.4	47.0	10.2	39.9	12.9	2.8

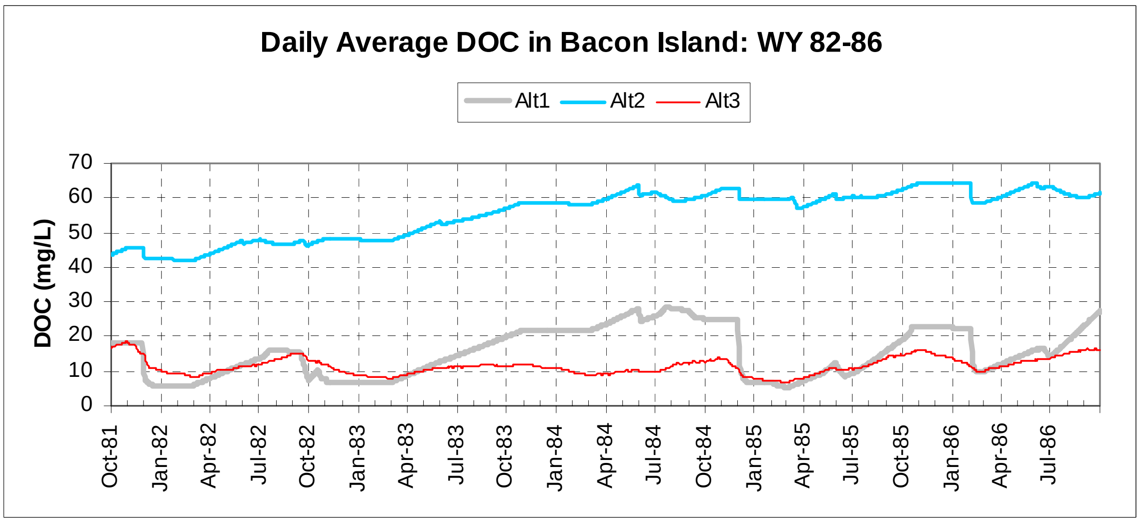
2.4.2 DOC at Urban Intakes

Maximum daily average DOCs at urban intake sites are given in Table 2.6. While it is clear that there is a direct response in increases of the DOC concentration at the four major urban water supply intakes to Bacon Island and Webb Tract releases, the significance of those releases and possible operational limitations are less clear. When considering any of the results, it is important to keep in mind the concentration of DOC on both island reservoirs associated with the releases as well as the timing and duration of the releases.

Table 2.6: Maximum Daily Averaged DOC (mg/L)

Location	Base	Alt 1	Alt 2	Alt 3
Old River at Rock Slough (RS)	11.31	11.31	11.31	11.32
Old River at Los Vaqueros Intake (LVR)	11.30	12.98	22.13	11.30
Banks Pumping Plant (SWP)	11.31	12.02	11.32	11.31
Tracy Pumping Plant (CVP)	11.13	11.13	15.21	11.13





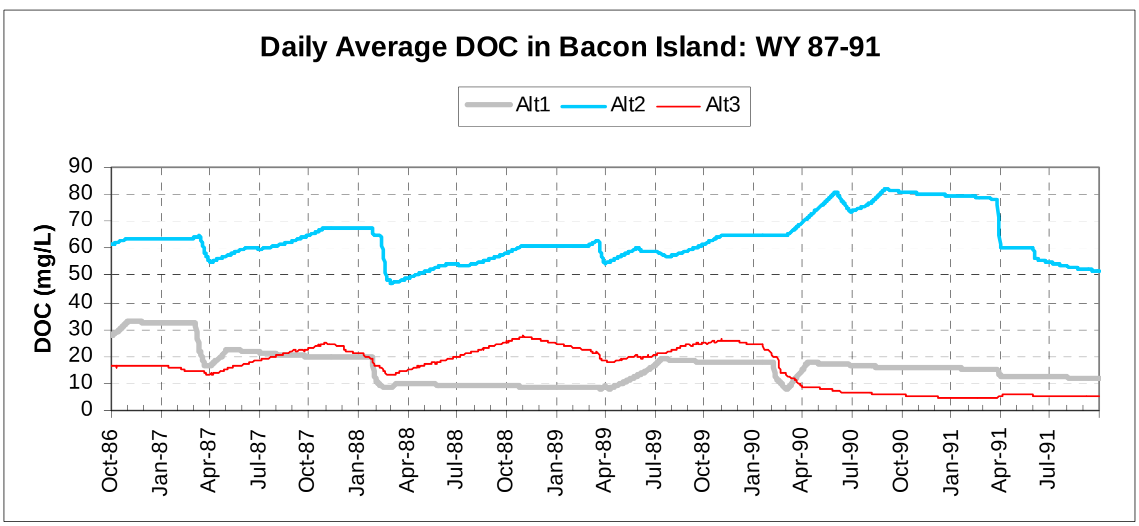


Figure 2.7: Daily Average DOC in Bacon Island

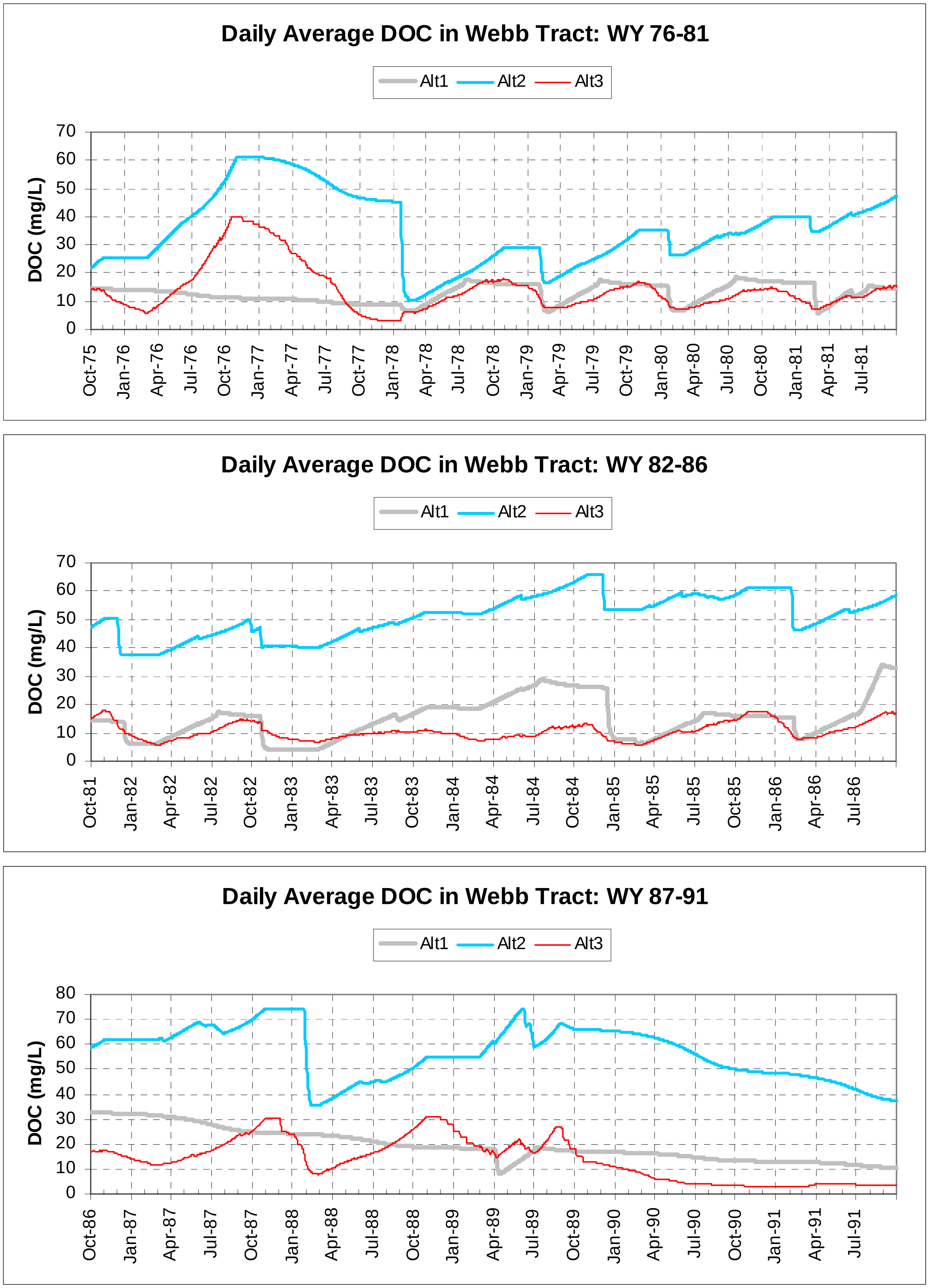


Figure 2.8: Daily Average DOC in Webb Tract

Although no project islands were simulated in the base case scenario, the maximum daily averaged base DOC concentrations around 11 mg/L at all of the urban intakes are associated with high winter time runoff. With the exception of Rock Slough, the maximum daily averaged DOC concentrations shown below are all associated with release periods.

The 14-day average DOC constraints called for by the Delta Wetlands WQMP were calculated every day as the average of the 14 previous days (WQMP, 2000). This was done not only to remain consistent with CALSIM, but also under the assumption that while operation of the project would be managed in real-time, that limitations of real-time forecasting and operations would make use of the previous 14 days worth of data. Though the calculation of the 14-day running averages resulted in a significant decrease in the Alt 2 (Table 2.7) DOC concentrations, the maximum concentrations for the other alternatives are still larger than the maximum values for the base case. This is result is expected, the CALSIM II operations for Alt 2 were designed to meet the 14-day running average standards, while the other alternatives were either concerned with maximizing project yield without consideration to the DOC constraints or minimizing the concentration of DOC inside the island reservoirs (under the assumption that lower DOC concentrations from the island reservoirs will result in additional times that the project water can be used to supplement SWP and CVP yield).

Table 2.7: Maximum 14-Day Running Average DOC (mg/L)

Location	Base	Alt 1	Alt 2	Alt 3
Old River at Rock Slough (RS)	10.78	10.84	10.90	10.89
Old River at Los Vaqueros Intake (LVR)	10.63	11.48	12.06	10.75
Banks Pumping Plant (SWP)	10.77	10.88	10.84	10.85
Tracy Pumping Plant (CVP)	11.00	11.02	11.18	11.02

The 14-Day average time series plots of the DOC for all alternative scenarios are given in Figures 2.9a through 2.9d. The results show that violations of the WQMP DOC standard are not based on the absolute 14-day averages, but instead on the difference between the alternative and base operations (WQMP, 2000). According to the WQMP, when the modeled base case DOC is less than 3 mg/L or greater than 4 mg/L, the maximum increase in DOC is 1 mg/L. When the base case DOC is between 3 mg/L and 4 mg/L, then the alternative DOC can not exceed 4 mg/L (in other words, the maximum allowed increase is the difference between 4 mg/L and the base case). The incremental WQMP DOC constraint is illustrated in Figure 2.10.

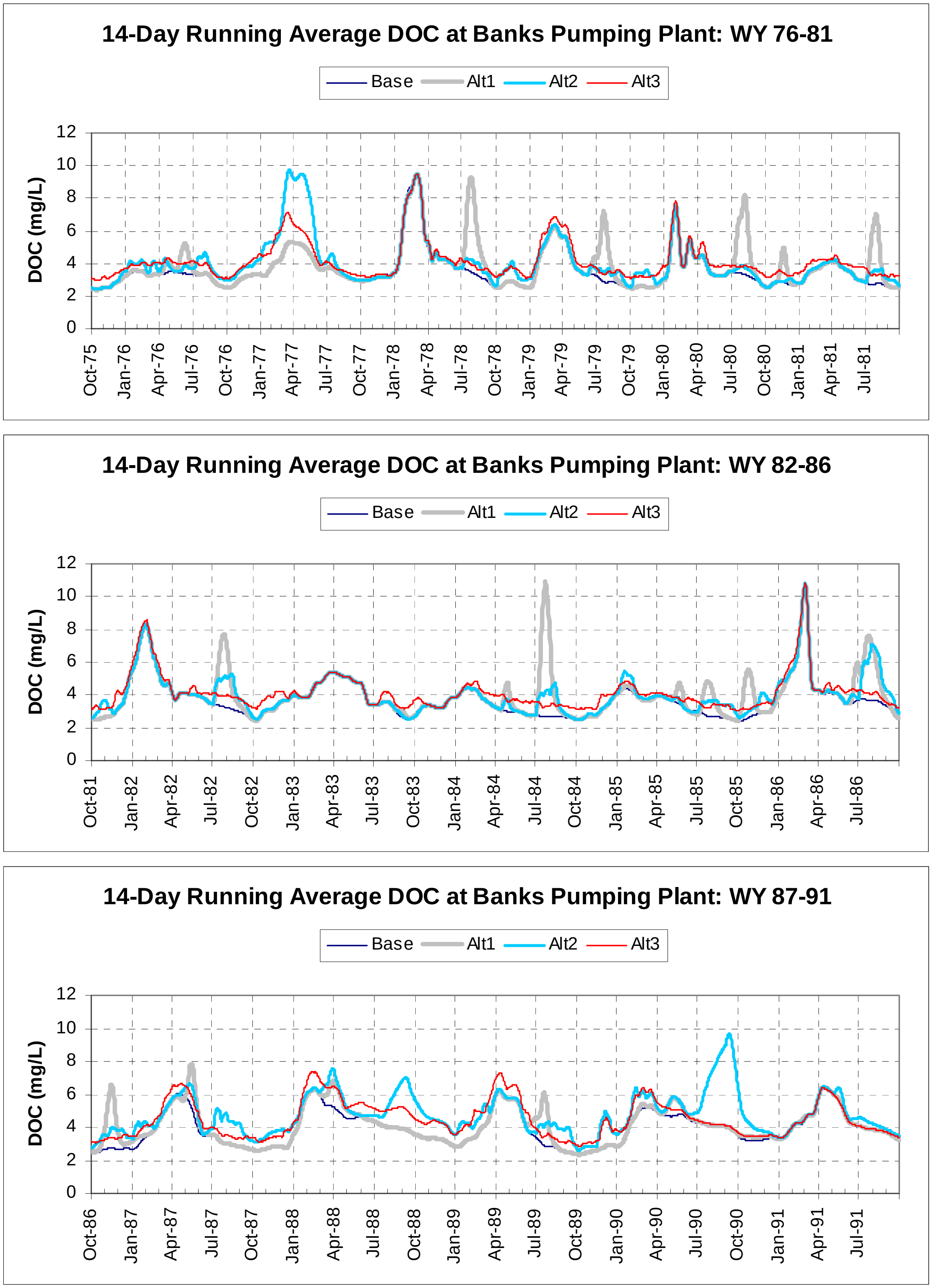


Figure 2.9a: 14-Day Running Average DOC at Banks Pumping Plant

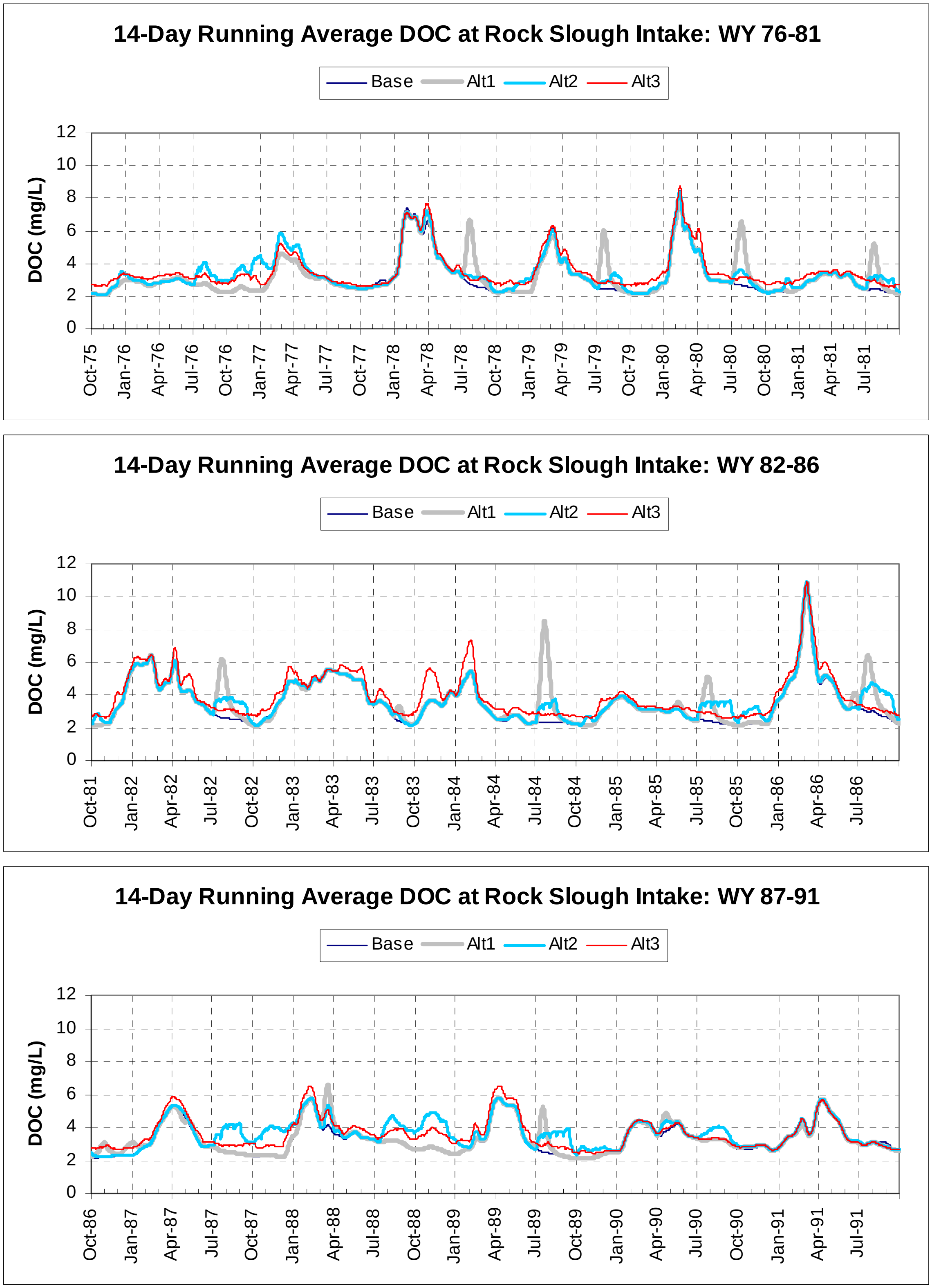


Figure 2.9b: 14-Day Running Average DOC at Rock Slough Intake

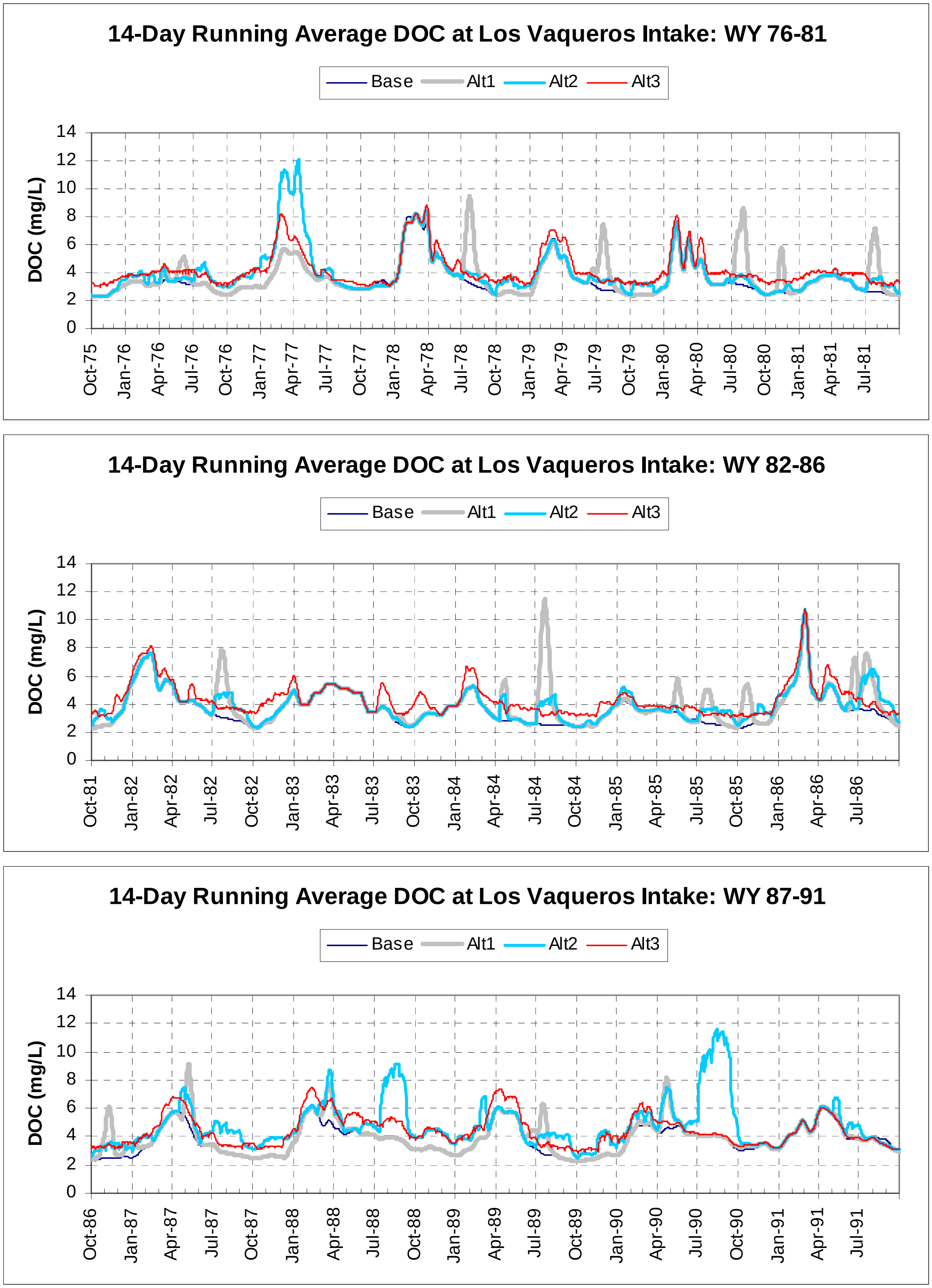
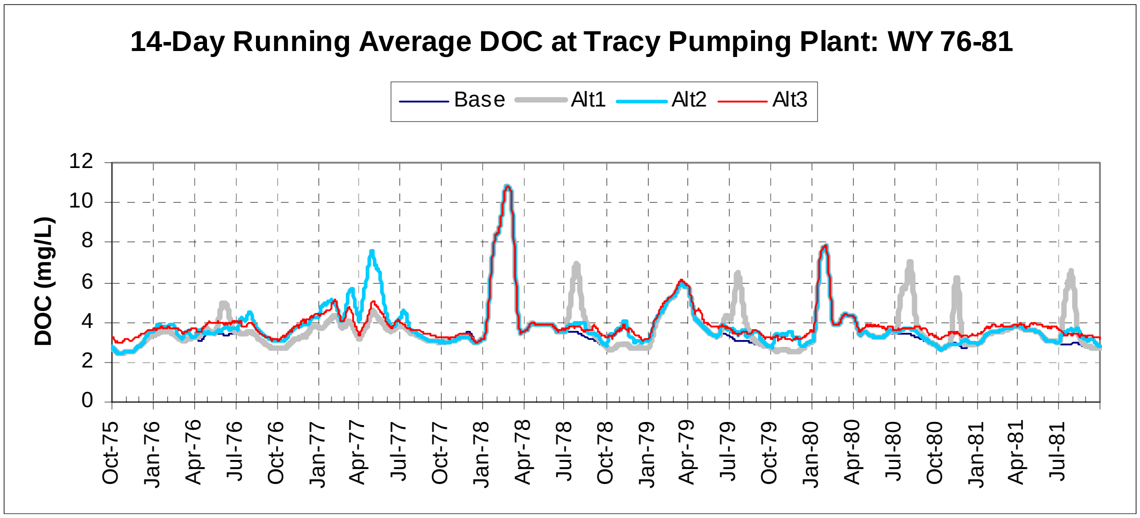
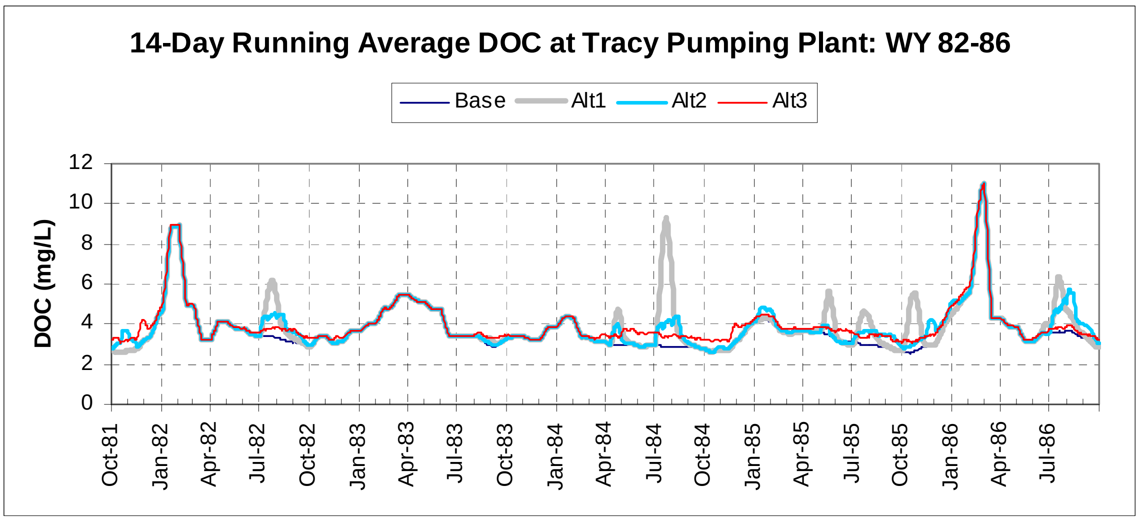


Figure 2.9c: 14-Day Running Average DOC at Los Vaqueros Intake





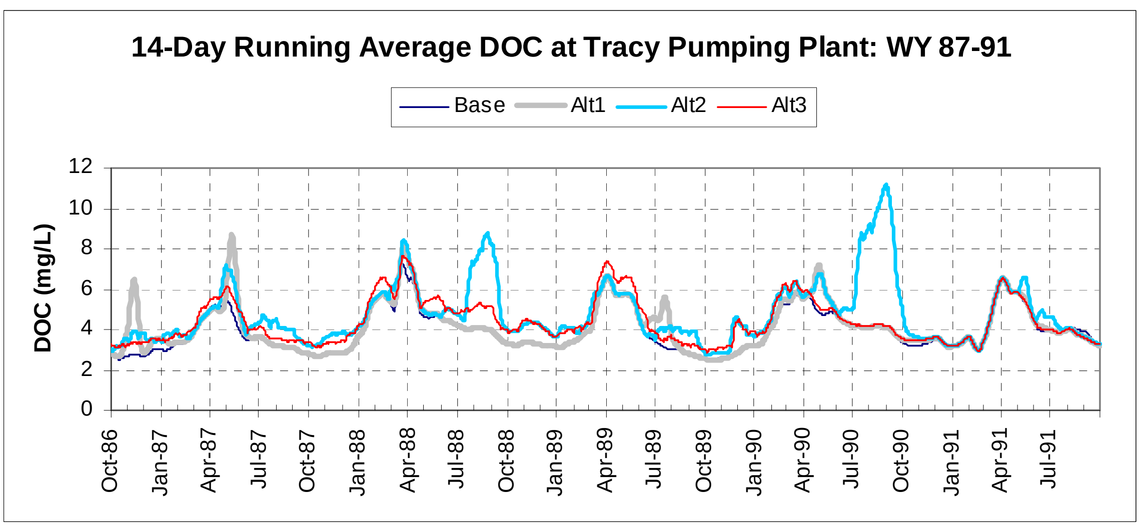


Figure 2.9d: 14-Day Running Average DOC at Tracy Pumping Plant

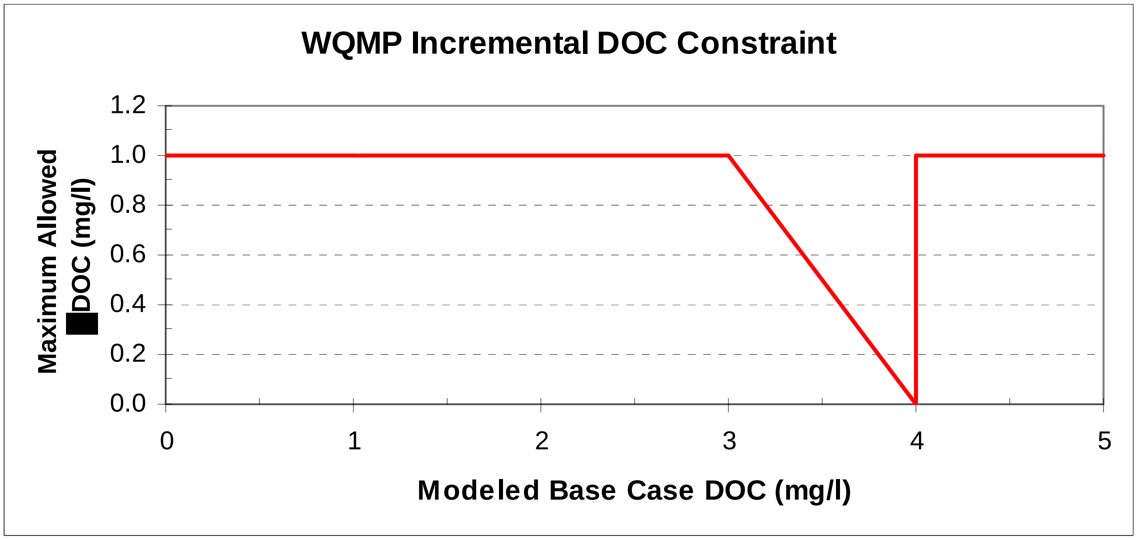


Figure 2.10: WQMP Incremental DOC Constraint

The first step to calculating the frequency of violations for each alternative (i.e. the number of days the 14-day average exceeds the WQMP incremental DOC constraint) is to first just calculate the change in DOC due to operation of the project. Although the constraint is variable, this information is valuable in examining the nature of the impact of each alternative. Although it was shown that the largest maximum DOC concentrations are associated with Alt 2, with the exception of the Tracy Pumping Plant the largest differences in DOC are associated with Alt 1 (Table 2.8). This difference is due both to the timing of releases in Alt 1 and Alt 2 as well as the magnitude of the releases. The stage plots shown in Figures 2.3 and 2.4 indicate that when the project is operated without considering any DOC constraints that more water is released from the reservoirs. And since the reservoir island DOC is typically higher than the DOC in the surrounding channels, the Alt 1 impact is greater.

Table 2.8: Maximum Increase (Alternative - Base) in 14-Day Running Average DOC (mg/L)

Location	Alt 1	Alt 2	Alt 3
Old River at Rock Slough (RS)	6.21	2.14	2.01
Old River at Los Vaqueros Intake (LVR)	8.93	7.52	2.91
Banks Pumping Plant (SWP)	8.22	5.70	1.96
Tracy Pumping Plant (CVP)	6.44	7.06	1.64

The time series difference plots for all alternatives and for all intakes are shown in Figures 2.11a through 2.11d.

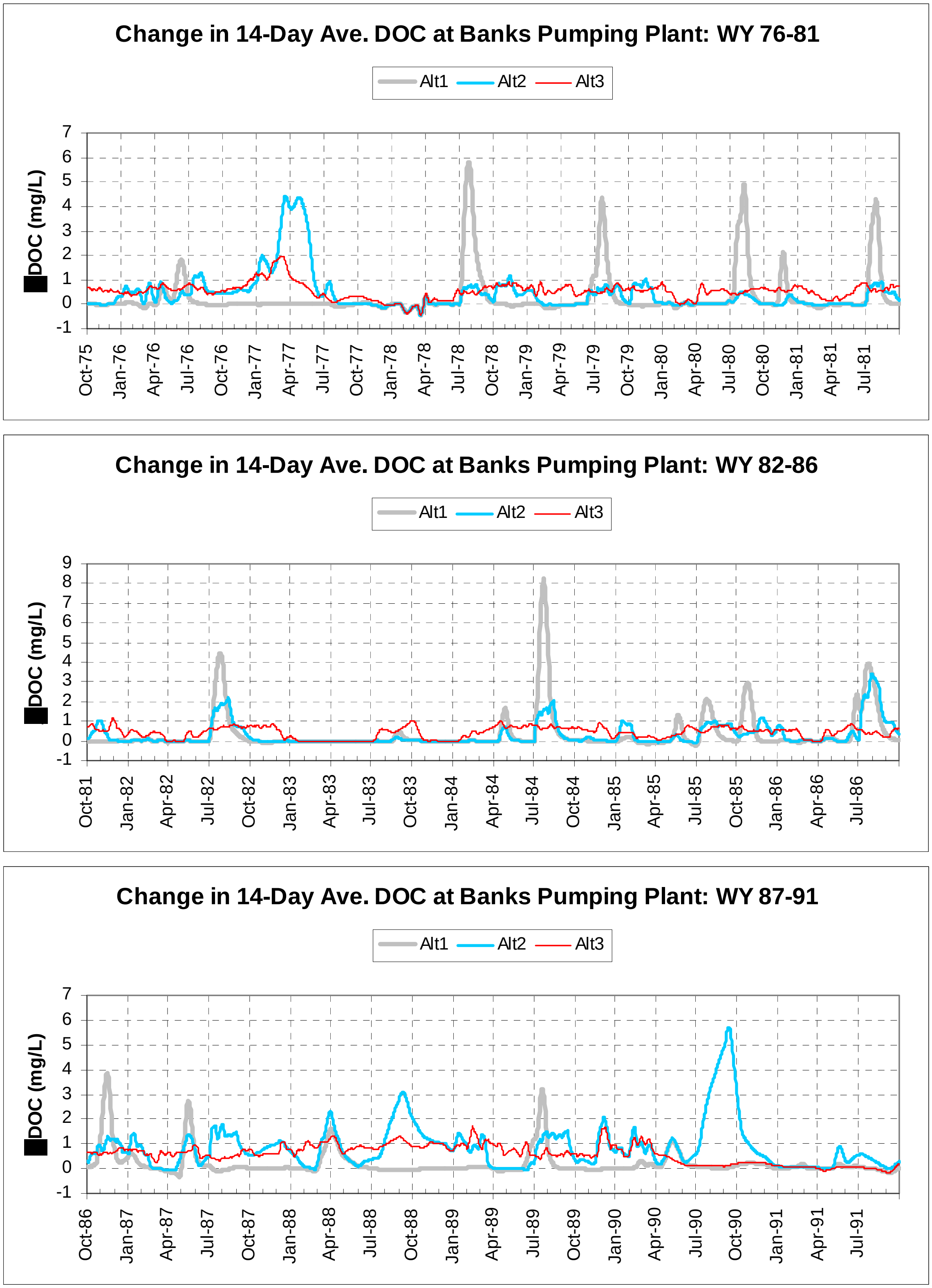
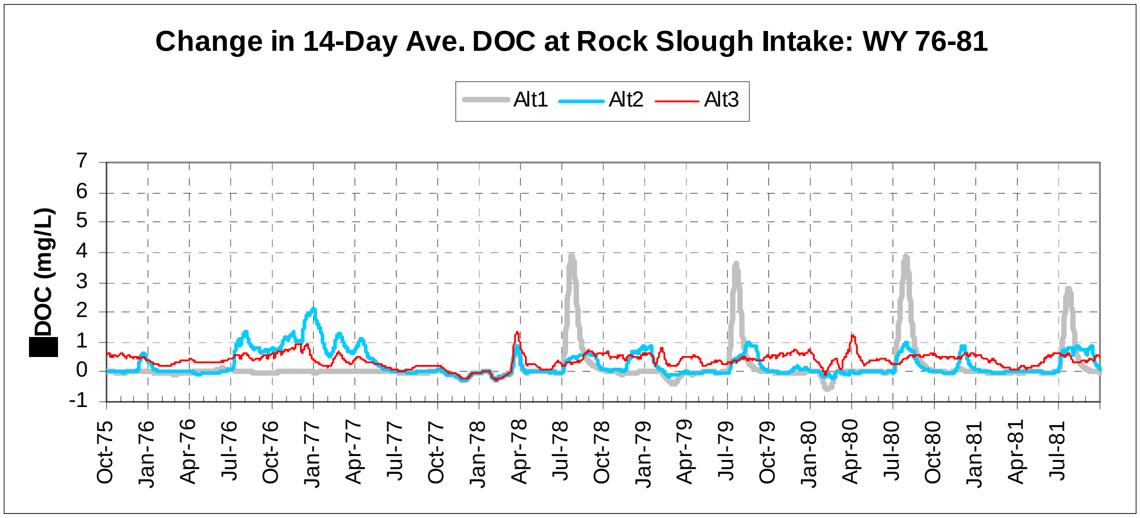
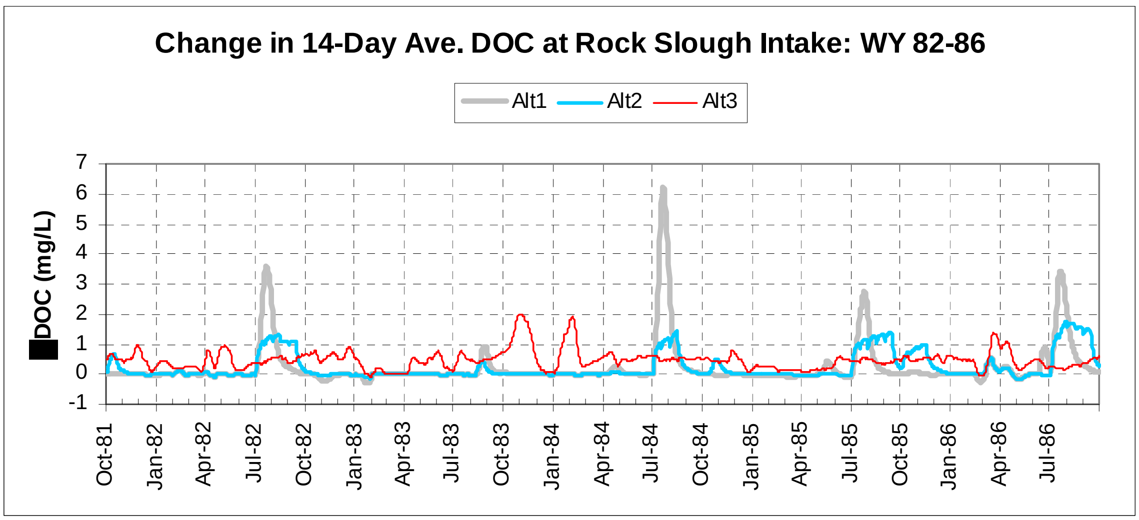


Figure 2.11a: Change in 14-Day Ave. DOC at Banks Pumping Plant





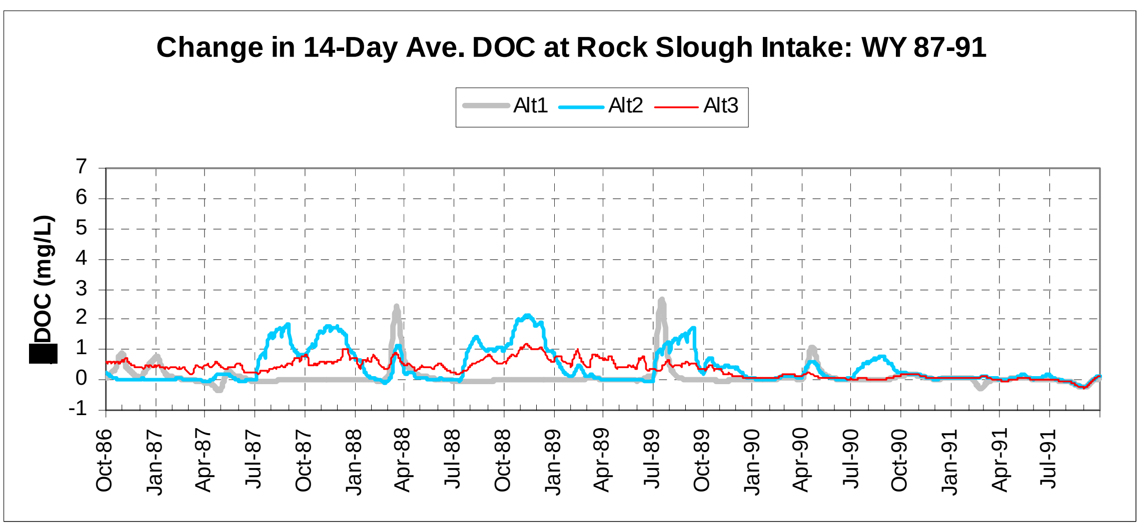


Figure 2.11b: Change in 14-Day Ave. DOC at Rock Slough Intake

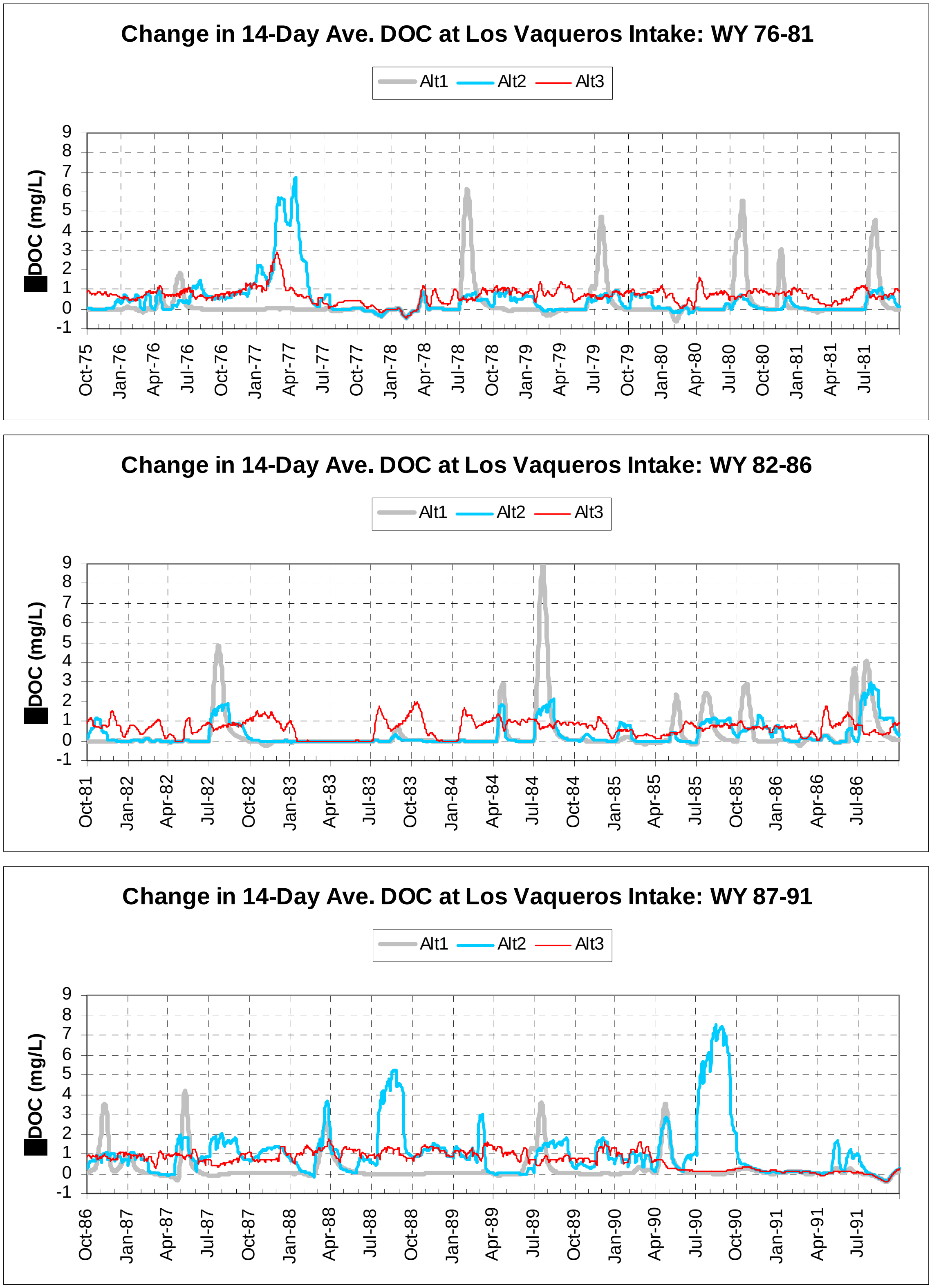


Figure 2.11c: Change in 14-Day Ave. DOC at Los Vaqueros Intake

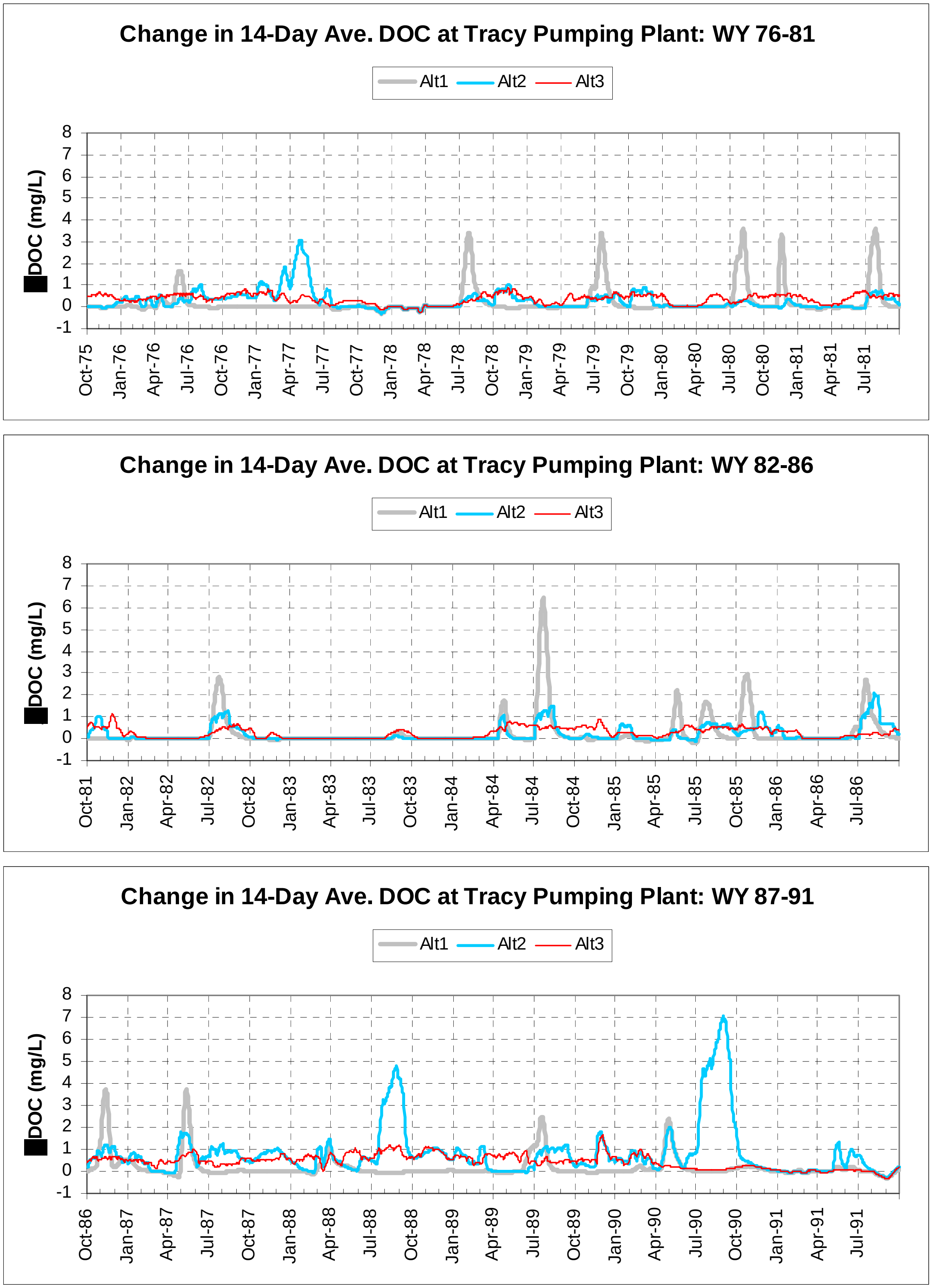


Figure 2.11d: Change in 14-Day Ave. DOC at Tracy Pumping Plant

The flexibility of each alternative can also be examined by calculating a cumulative distribution function (cdf) from the frequency histograms (not shown) of the change in DOC for the entire simulation period. Each cdf represents the relative change in DOC for all of the alternatives. By assuming a given or acceptable change in DOC threshold, the percentage of time that each alternative will result in a change in DOC equal to or less than this threshold is shown. A preferred alternative will tend to be shifted to the upper right corner of the plots.

The cdf for change in DOC for all intake sites are shown in figures 2.12a through 2.12d. The results show that the increase in DOC due to the operation simulated in Alt 3 is less than 1 mg/L 93% of the time. For this same limit, the increase in DOC due to Alt 2 is less 1 mg/L only 83% of the time. However, the increase in DOC due to Alt 3 is less than 0.0 mg/L only 6% of the time, whereas the increase in DOC due to Alt 2 is less than 0.0 mg/L 21% of the time. In other words, even though Alt 2 is more likely to result in a change greater than 1 mg/L, the change in DOC due to Alt 2 is more likely to be negative (i.e. a potential water quality benefit due to project operations).

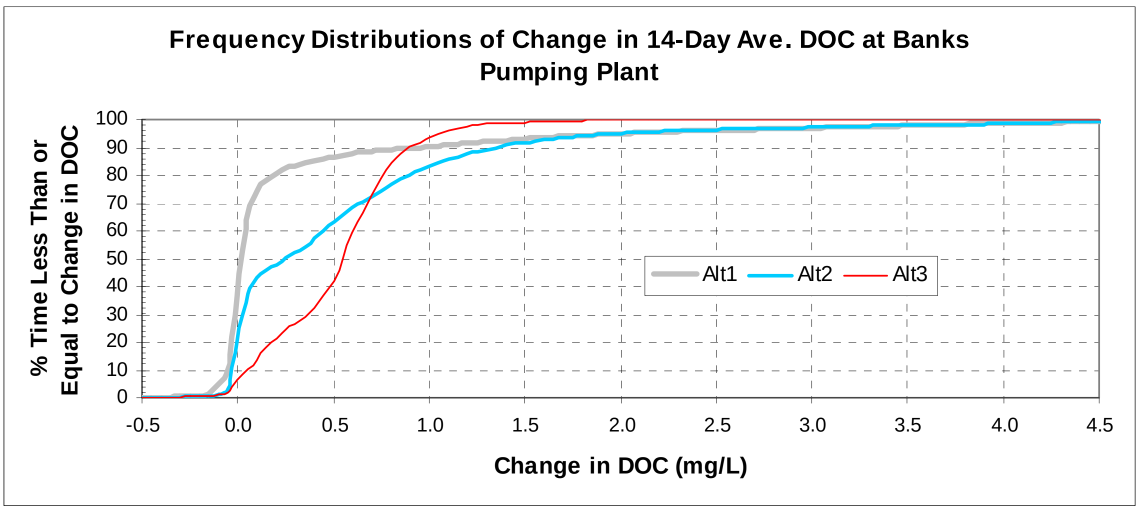


Figure 2.12a: Frequency Distribution of Change in 14-Day Ave. DOC at Banks Pumping Plant

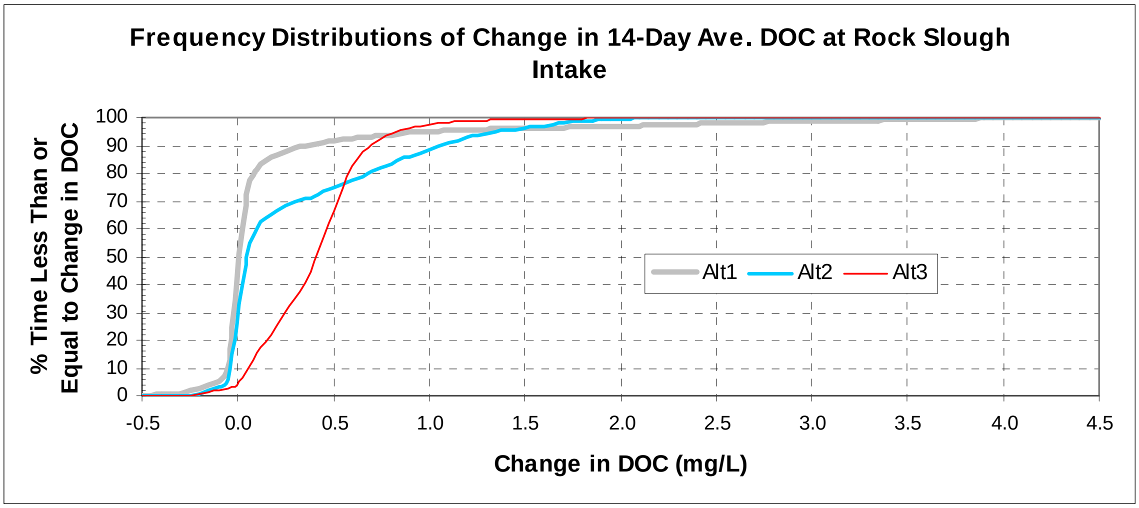


Figure 2.12b: Frequency Distribution of Change in 14-Day Ave. DOC at Rock Slough Intake

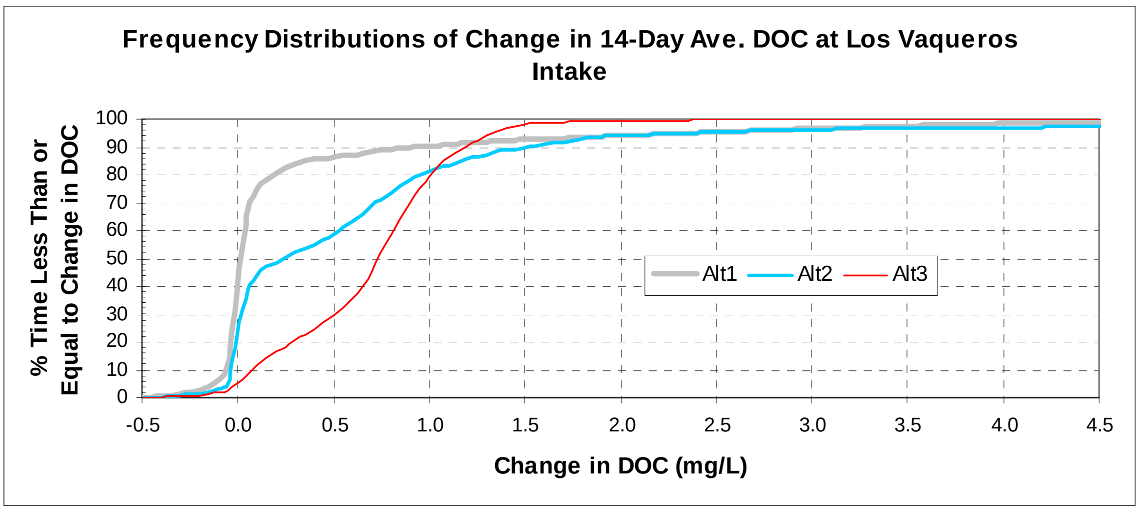


Figure 2.12c: Frequency Distribution of Change in 14-Day Ave. DOC at Los Vaqueros Intake

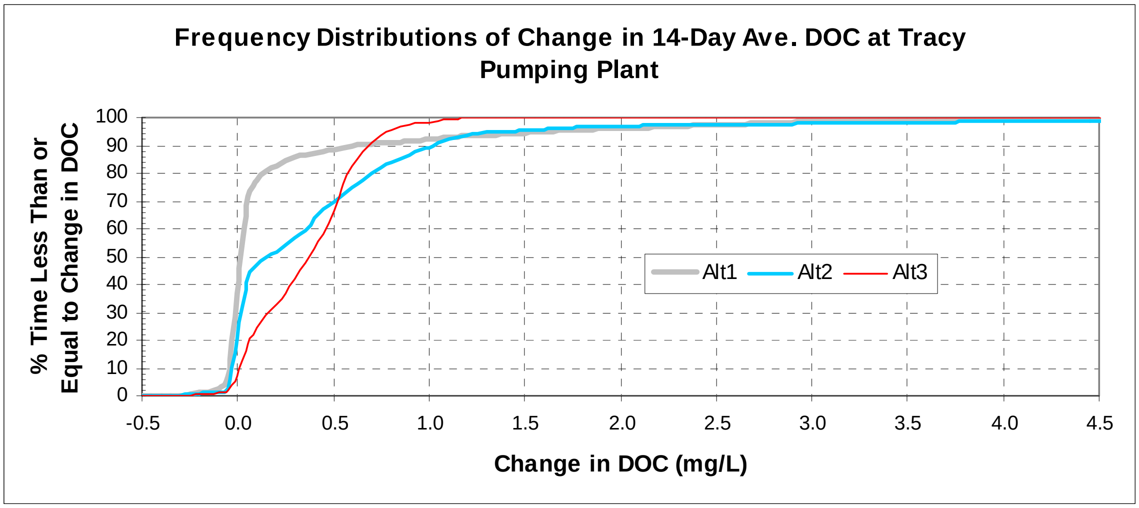


Figure 2.12d: Frequency Distribution of Change in 14-Day Ave. DOC at Tracy Pumping Plant

The probability of the change in the 14-day running average DOC exceeding 1 mg/L is shown in Table 2.9. It is important to bear in mind that 1 mg/L is maximum allowed change, and when the base case DOC approaches 4 mg/L, that the WQMP constraint is more conservative. In other words, the frequency of violations of the WQMP DOC constraints is actually higher than these probabilities.

Table 2.9: Probability of Change in 14-Day Running Average DOC Exceeding 1 mg/L

Location	Alt 1	Alt 2	Alt 3
Old River at Rock Slough (RS)	5%	12%	3%
Old River at Los Vaqueros Intake (LVR)	10%	19%	20%
Banks Pumping Plant (SWP)	10%	17%	7%
Tracy Pumping Plant (CVP)	8%	11%	2%

The actual number and frequency of days that the 14-day average DOC for each alternative violated the WQMP standard for all four urban intakes is shown in Table 2.10. A total of 5,844 days were simulated in the 16-year run. The first 14 days' running averages were calculated using model results taken from the warm-up period.

Alt 3 had the largest number of violations for Los Vaqueros, however it is important to note that CALSIM II lumps the Contra Costa Water District (CCWD) demands together. Under the current DSM2 planning procedure, the combined CCWD diversions are all assumed to be at Rock Slough. However, it stands to reason that the Old River at Los Vaqueros Intake (LVR) location would experience the highest number of violations, as the DSM2 output location for LVR is on the Old River. Previous Particle Tracking Model (PTM) simulations have suggested that particles released from Bacon and Webb island tend to flow down the Old River, thus increased exports at either Banks or Tracy pumping plants will tend to increase the flow past LVR.

Table 2.10: Number and Frequency of Days the DOC Constraint is Exceeded

Location	Alt 1		Alt 2		Alt 3	
	# Days	% Days	# Days	% Days	# Days	% Days
Old River at Rock Slough (RS)	350	6%	802	14%	421	7%
Old River at Los Vaqueros Intake (LVR)	643	11%	1343	23%	1856	32%
Banks Pumping Plant (SWP)	653	11%	1322	23%	1148	20%
Tracy Pumping Plant (CVP)	575	10%	1025	18%	439	8%

2.4.2 Other Conservative Constituents

Earlier studies suggest that strong correlation exists between EC, DOC and other conservative constituents (Cl, Br, TOC, UVA and TTHM) in the Delta. As described earlier, DOC can be used as a surrogate for TOC and chloride and bromide can be derived using EC. Similarly, statistical relationships have been developed between UVA and DOC. Simulated DOC and bromide, UVA values, and approximate water temperatures were used to compute TTHM concentrations. Thus, the conservative constituents being a function of DOC and EC, DSM2 studies were not repeated for these constituents. The results for these constituents are given in Appendix C and are based upon the 2002 studies. Even without planned recirculation and old DOC growth algorithm, the violations of the water quality standards for these constituents are minimal. With the revised operation rules, the DOC concentration at the key delta location has reduced significantly and so will be concentration of other constituents.

2.5 Conclusion and Recommendation

2.5.1 Conclusion

Based upon the DSM2 water quality modeling, the following conclusions could be inferred.

- The DOC concentration in the project island is both a function of the mixing associated with diversions to the islands, the production of organic carbon mass from algae and wetlands plants, and the addition of organic carbon mass due to leaching and microbial decay of the peat soils. The recirculation operation mitigates the effect of DOC growth within the island.
- The 14-day average DOC is within the WQMP 14-day standard. However, some violations were observed on the difference between the alternative and base operations.
- The increase in DOC due to the recirculation operation is less than 1 mg/L 93% of the time.

2.5.2 Recommendations

The following recommendations were made to improve the results of the DSM2 model studies.

- Permanent barriers were included in all four simulations, however, the operation (i.e. timing) of the barriers were based on the different operations. A schedule and description of what the operation of the barriers for each scenario is critical to understanding the flow patterns in the South Delta and can have an impact on the fate of particles released from the project islands.

- Implement and refine CALSIM2 water quality operating rules through iteration with DSM2.
- DSM2-PTM was run for Alt 1 in order to improve the CALSIM II DOC constraints. The fate of particles released from both islands was used along with export / inflow ratio information taken from CALSIM to develop relationships estimating how much of the organic carbon released from either island made it to Banks and Tracy pumping plants. Reiteration of the CALSIM and DSM2 runs will improve the results.

2.6 References

California Department of Water Resources. (1995a). Estimation of Delta Island Diversions and Return Flows. Division of Planning. Sacramento, CA. February.

California Department of Water Resources. (1995b). Representative Delta Island Return Flow Quality for DSM2. Division of Planning. Sacramento, CA. May.

California Department of Water Resources. (2001). Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. Twenty-Second Annual Progress Report to the SWRCB, Chapters 3 and 10, Office of State Water Project Planning. Sacramento, CA. August.

California Department of Water Resources. (2002). Water Quality Modeling Technical Appendix, Integrated Storage Investigations In-Delta Storage Feasibility Study. Office of State Water Project Planning. Sacramento, CA. May.

Integrated Storage Investigations. (2002a). In-Delta Storage Feasibility Study Summary Report, May.

Integrated Storage Investigations. (2002b). In-Delta Storage Feasibility Study Report on Operation Studies, May.

Jones and Stokes Associates (2000). Delta Wetlands Final Environmental Impact Report, Sacramento, CA. May.

Jung and Associates (2000). Revision of Representative Delta Island Return Flow Quality for DSM2 and DICU Model Runs, Municipal Water Quality Investigation Program. Prepared for the California Department of Water Resources – Division of Planning and Local Assistance, Sacramento, CA. MWQI-CR#3, December.

Water Quality Management Plan. (2000). Protest Dismissal Agreement between CCWD and Delta Wetlands Properties, Exhibit B. October.

DuVall, R. (2003). "In-Delta Storage Program Water Quality Field Investigations." Presentation on Jan. 22, 2003 to stakeholders committee meeting. Available at: http://www.isi.water.ca.gov/ssi/indelta/docs/4%20FieldInvStakeholders012203.ppt. Sacramento, CA.

Mierzwa, M. (2002). "DSM2 Evaluation of In-Delta Storage Alternatives." Technical report dated April 18, 2002. California Department of Water Resources. Sacramento, CA.

Mierzwa, M. and G. Pandey. (2003). "Chapter 7: Implementation of a New DOC Growth Algorithm in DSM2-QUAL." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 24th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

Chapter 3: WATER QUALITY FIELD INVESTIGATIONS

3.1 Introduction

Disinfection byproducts (DBPs) such as trihalomethanes are an issue of concern for the California water system and the In-Delta Storage Program. Maximum contaminant levels and operational criteria are set by regulatory agencies (e.g., D1643 and WQMP) to protect public health and research is being conducted better understand and manage DBP precursors like total and dissolved organic carbon (TOC and DOC) at their source.

Field investigation during the feasibility stage of the study focused on better understanding the reservoir biological processes concepts and variations in organic carbon due to peat soils and biological productivity. The field investigations included the following specific tasks to estimate the organic carbon loading from peat soils and biological productivity.

- Reviewed the literature on organic carbon loading in the Delta for information that may be applicable to In-Delta storage.
- Evaluated likely Organic Carbon (OC) concentrations and loads expected in storage water using mesocosms or physical models of the proposed reservoir islands. The experiments were extended to simulation of water circulation in reservoirs to resolve the water quality issues.
- Integrated results from field studies with mathematical models (CALSIM II, DSM2, and DYRESM) to resolve water quality issues and develop desired operations for overall system benefits.

3.1.1 Development of Conceptual Model

DOC and particulate organic carbon (POC) in surface water can come from external or internal sources. For reservoir construction in wetlands, soil could be a dominant source of OC loading, at least initially. In order to adequately predict and mitigate both short-term and long-term impacts associated with flooding peat soils, it is important to understand not just the likely quantity of OC loading but also the quality or sources of that loading. A simplified conceptual model showing the sources of major biological and physical factors in the reservoir DOC is shown in Figure 3.1.

Mesocosms or physical models of the proposed reservoir islands were created to study the ecological processes driving OC loading. This mesocosm study was designed to meet specific needs and timelines of the program. The focus of the study was to reduce uncertainty surrounding estimates of likely rates for the process of OC loading in the proposed reservoir islands. The mesocosms were put together using naturally occurring water and biota. The objective of the experimental design was to include as many complex and interacting ecological factors that drive carbon dynamics in the Delta as possible. Study results in terms of net OC loading rates (such as interacting processes like abiotic leaching, microbial degradation, photooxidation and macrophyte growth and death decomposition) were considered together. Nevertheless, the use of water depth as a treatment variable with the mechanism of light attenuation driving submersed macrophyte growth in a replicated, controlled mesocosm experiment provided a start for fleshing out qualitative and quantitative differences in OC sources.

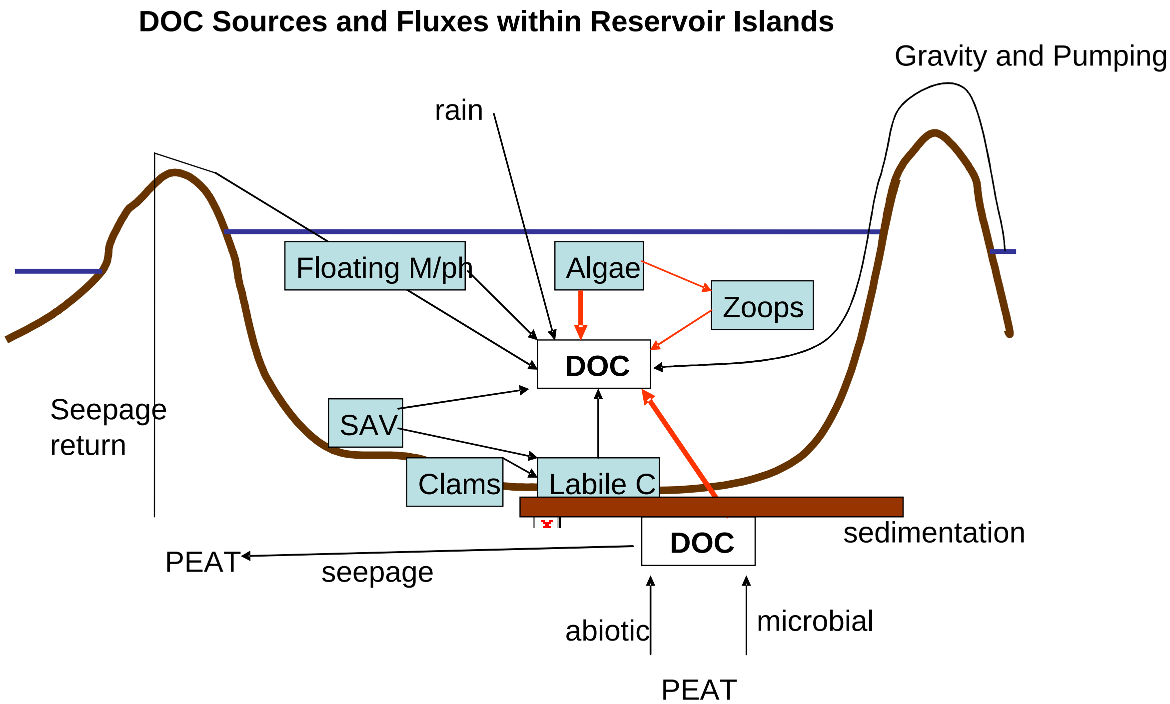


Figure 3.1: Conceptual Model Showing the DOC Sources in Project Island

3.2 Materials and Methods

Mesocosm studies were conducted from March through December 2002 at the Municipal Water Quality Investigations Field Support Unit in Bryte, California (Plate 3.1). Four 3300 L (shallow) and four 6100 L (deep) mesocosms were put together using fiberglass tanks (1.5 m diameter and 1.8 or 3.4 m height respectively). The eight tanks (mesocosms) were filled with 820 L (0.5 m depth) of peat soil, classified as Rindge series muck (Plate 3.2), collected from Bacon Island, California, the site for one of the proposed reservoirs, on March 5, 2002. Before adding the soil to the tanks, living plant material was removed and the soil was well mixed using a front end loader and backhoe (Plate 3. 3). The Division of Natural Resources Analytical Laboratory at the University of California, Davis analyzed the soil for the following analytical groups: salinity, fertility, extractable micronutrients and exchangeable cations. Information on the lab and their analytical methods is available at (http://danranlab.ucdavis.edu/). In addition to these analyses, the % carbon (C), % hydrogen (H) and % nitrogen (N) content of the soil was determined using a Perkin-Elmer model 2400 CHN analyzer with acetanilide used as a standard. Soil fresh weight (fw) % moisture, % ash and % organic matter (OM) as well as dry weight (dw) % ash and % OM and loose soil bulk density were also determined before the soil was added to the tanks (Table 1). The soil was compacted somewhat once inside of the tanks by walking on it as it was applied, leveled and adjusted to the 0.5 m depth.

Plate 3.1: Fiberglass Mesocosms


Plate 3.2: Peat Soil (Rindge Muck) Sample


Plate 3.3: Backhoe and Dump Trucks at Bacon Island

On March 12, 2002 the tanks were filled with Sacramento River water collected at West Sacramento using a 11,355 L water truck. Once filled, the depth of water over the peat soil was approximately 1.4 m in the shallow mesocosms and 2.9 m in the deep mesocosms. An additional 6,100 L tank was filled with river water only (no soil) and served as a control mesocosm. The water was baffled during filling to reduce soil disturbance. Nevertheless, some mixing of the soil with the overlying water occurred for a few days after the tanks were filled as gas bubbles escaped from the soil and entrained soil particles in the water column. Secchi disk visibility was less than 0.3 m in the days following filling. Two weeks after filling most of the suspended soil particles settled out and Secchi disk visibility increased to one meter (data not shown). Turbidity measurements of water in the mesocosms are presented in Figure 3.2.

Table 3.1: Physical and Chemical Properties of the Peat Soil

Table 1. Physical and chemical conditions of the peat soil used in the experiment.

Analyte	Result	Unit	Reporting Limit
SP[a]	126	%	1
EC	2.98	mmhos/cm	0.01
pH	4.3	pH units	0.1
Ca (SP)	17.5	meq/L	0.1
Mg (SP)	12.1	meq/L	0.1
Na (SP)	5.8	meq/L	0.1
Cl (SP)	3	meq/L	0.1
HCO_3 (SP)	0.6	meq/L	0.1
CO_3 (SP)	<0.1	meq/L	0.1
SO_4-S (SP)	356	ppm	1
NH_4-N	37.5	ppm	0.1
NO_3-N	156	ppm	1
P-Olsen	73	ppm	0.1
Fe (DTPA[b])	688	ppm	1
Mn (DTPA[b])	10.4	ppm	0.1
Cu (DTPA[b])	0.6	ppm	0.1
Zn (DTPA[b])	1.6	ppm	0.1
X[c]-K	1	meq/100g	0.1
X[c]-Na	1.4	meq/100g	0.1
X[c]-Ca	19.6	meq/100g	0.1
X[c]-Mg	6.8	meq/100g	0.1
Soil Density[d]	0.743	Kg/L	1
Soil Moisture	40	%	NA
Organic Matter (dw)[e]	45	%	NA
Ash (dw)[e]	55	%	NA
Carbon[f]	26	%	NA
Nitrogen[f]	1.4	%	NA

[a] The saturation percentage (SP) method involves saturating the soil with water and subsequent extraction under partial vacuum of the liquid phase for the determination of dissolved salts. Soil moisture at the point of complete saturation is the maximum amount of water held when all the soil pore space is occupied by water and when no free water has collected on the surface of the paste.

[b] The DTPA (diethylenetriaminepentaacetic acid) micronutrient extraction method is a non-equilibrium extraction for estimating the potential soil availability of Zn, Cu, Mn and Fe.

[c] Equilibrium extraction of soil for plant available exchangeable potassium, sodium, calcium and magnesium using 1 Normal ammonium acetate (pH 7.0) and subsequent determination by atomic absorption/emission spectrometry

[d] The mass (743g) of 1L of fresh (not oven dried) non-compacted soil divided by 1KG

[e] By combustion of oven dried (70 C) soil in muffle furnace

[f] By CHN analyzer

The mesocosms were filled and drained according to typical modeled reservoir operations. Based on modeled operations, January is the most typical month in which sufficient water is available in the Delta to fill the reservoirs. Filling the tanks in early March was less representative of typical operations than a January fill but the unavoidable result of logistics constraints. The theoretical reservoirs are usually emptied in June and July to a minimum depth of 0.3 meters. The minimum depth is maintained by topping-off diversions. Filling and draining of the reservoirs usually takes two to four weeks depending on the pumping plant design (number of pumps and capacity). Because of logistics constraints and the late start, the tanks were filled in one day on March 12, 2002. The mesocosms were emptied by the same volume each day from July 29 through August 7 until a minimum depth of 0.3 m was reached, to better simulate how the reservoirs will be drained. As the mesocosms were drained, water pressure on the peat soil at the bottom was reduced and gas bubbles again escaped from the soil, mostly in the deep mesocosms. Note the dramatic increase in turbidity in the deep mesocosms after draining to a depth of 0.3 m (Figure 3.2). It was not clear if the gas was from air trapped in the soil when the tanks were initially filled or if the gas was from microbial activity or other sources. The mesocosms were maintained at a Depth of 0.3 m through the end of December except for the addition of rain water which increased the drained depth from 0.3 m to about 0.5 m in the last few weeks of the study. Rain did not have an obvious effect on the mesocosms during must of the study especially when the mesocosms were full and precipitation was only a small fraction (on the order of 1%) of tank volume. Rainfall data for Bryte, CA in are shown in Figure 3.3. River water was added at least monthly to make up for evaporation loss. The tanks were refilled in January 2003 and a second year of this study is currently underway. Similar reservoir operations with winter filling and summer draining were used in the second year's study but a small circulation flow (approximately 15% of reservoir water volume exchanged per month) was simulated in the mesocosms.

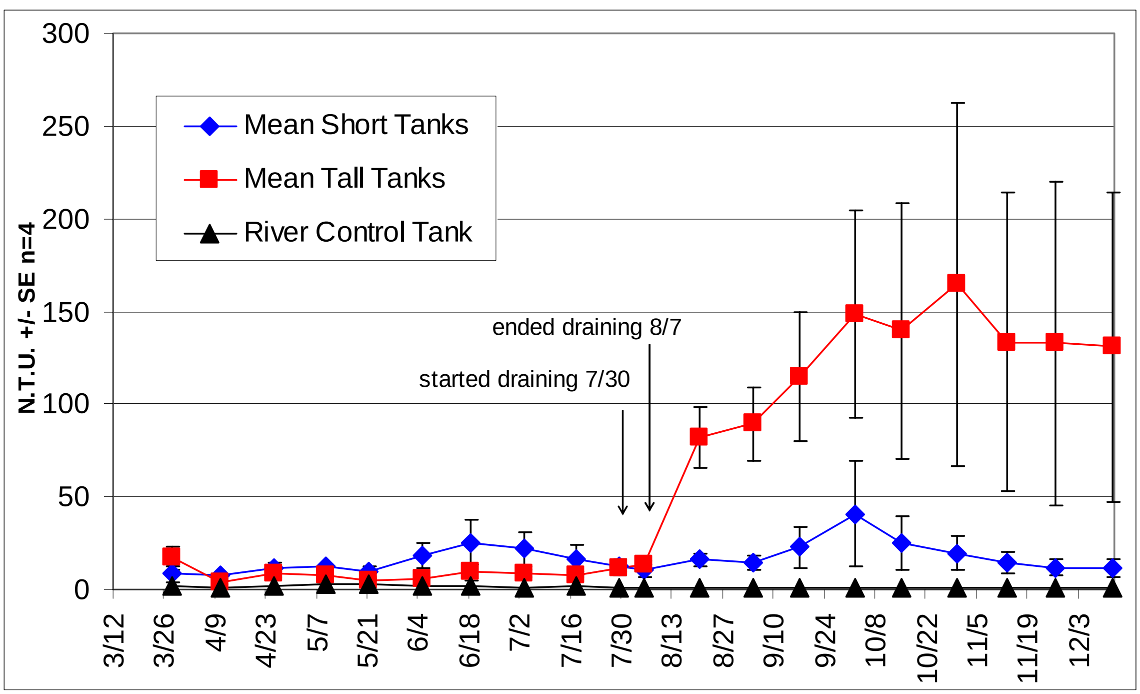


Figure 3.2: Mean Turbidity in Mesocosms in 2002

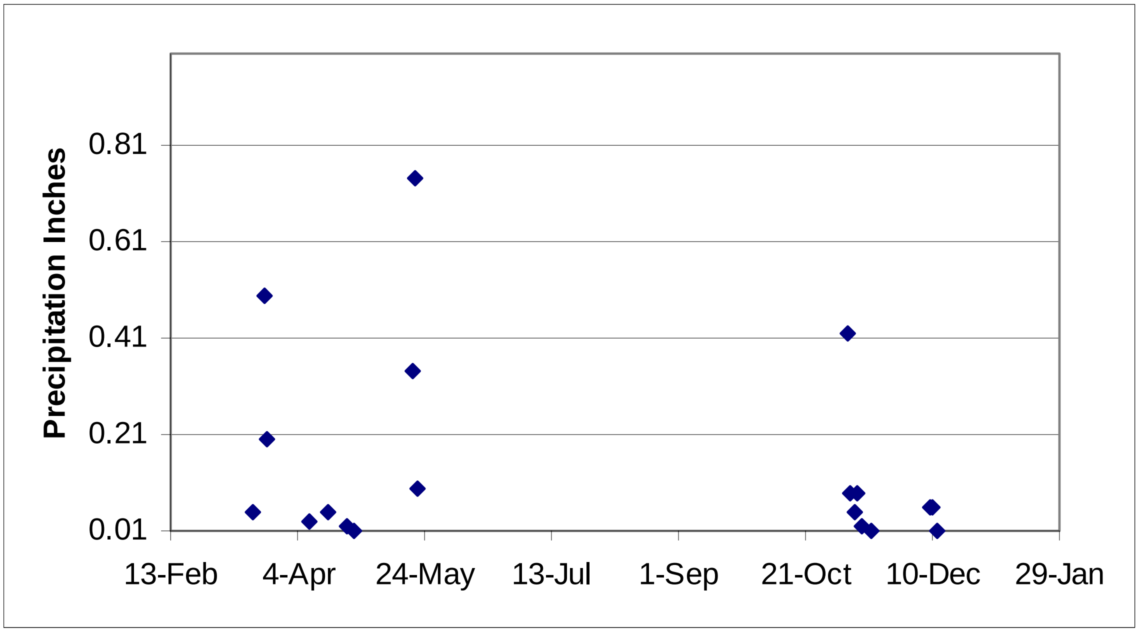


Figure 3.3: Daily Precipitation Totals for Bryte Station for 2003-2003

Disturbance or manipulation of the soil used to fill the mesocosms was not considered a problem in this study. The objective of the study was to physically model conditions in the proposed reservoir islands after flooding. Of the proposed reservoir islands' land areas, 85% to 90% is in production agriculture and subject to the disturbance of annual tilling. Tilling turns over approximately the top 30 cm of soil, the same surface layer of soil collected for this study. Note the vast area of tilled peat soil in the agricultural fields of Bacon Island shown in Plate 3.3. Peat soil on the reservoir islands will also be disturbed during construction of the integrated facilities, levee modification and excavation for borrow material (sand) located under the peat soil. This disturbed peat soil will form the soil/water interface when the islands are flooded. Gas bubbles will also escape from the reservoir soils when the islands are first flooded. In addition, the reservoirs will be filled through pumping facilities at a rate of 1500 cfs. This flowing water together with wind waves will cause some erosion and mixing of soil and water during filling. Nevertheless, the same soil and mesocosms were used in the second year's study. Other than the simulated reservoir diversions and discharges and the resulting release of interstitial gas bubbles, which will also occur in the real reservoir islands, disturbance did not occur in this subsequent year's study.

Soil from Bacon Island (one of the proposed reservoir islands) together with naturally occurring biota in the Sacramento River water as well as macrophytes, invertebrates and fish collected from the Delta were used in this study to create physical models (mesocosms) of the reservoir islands. Soil from one of the proposed reservoirs was used and provided inoculation of the mesocosms with appropriate seeds, eggs and organisms. The Sacramento River will be the source of most of the water diverted to the reservoir islands. Untreated water from this river was added to the tanks within an hour of collection in order minimize plankton mortality. The most common zooplankton that developed in the mesocosms were (in order of abundance): cyclopoid nauplii, *Acanthocyclops vernalis, Bosmina*, *Daphnia* and rotifers. Common phytoplankton included: *Ankistrodesmus, Synedra, Cryptomonas, Melosira, Chlorella, Chlamydomonas* and unidentified flagellates.

Egeria densa is probably the most abundant submersed macrophyte in the Delta although good diversity and abundance data do not exist for submersed or other aquatic plants in the Delta (Jassby and Cloern 2000). After observing the onset of active growth of *Egeria* in the Delta, fragments were collected from Franks Tract and added to the mesocosms that same day, April 17, 2002. Ten fragments (total 80 g f.w.) were added to each mesocosm. Naturally occurring invertebrates, epiphytic algae, eggs or other organisms on the *Egeria* fragments were not removed and the fragments were transported in coolers filled with Delta water to minimize mortality. Light levels in the mesocosms were approximately 550 and 150 μmol m^{-2} s^{-1} at depths of 0.3 and 1.0 m respectively in the mesocosms. In the deep mesocosms, light levels were less than 50 μmol m^{-2} s^{-1} at depths over two meters and were probably too low to support *Egeria* growth. In May 2003 however, an *Egeria* stem was observed growing up to the surface in one of the deep mesocosms. Light levels may have been higher, high enough to support growth of any surviving *Egeria*, when the mesocosms were in a drained (0.3 m depth) condition from August 2002 to January 2003.

On May 1, eleven adult Threespine stickleback were added to each mesocosm. These fish were selected because they are naturally occurring in the Delta and they satisfied mosquito concerns of the County vector control district. *Gambusia* populations unexpectedly appeared in the mesocosms and it is not clear if these recruits got in with the Threespine stickleback, the river water, *Egeria* fragments or otherwise. Minnow traps were used to remove the fish from the mesocosms before draining. Trapping was stopped when fish were no longer caught. More *Gambusia* than threespine sticklebacks were caught in the traps. Some adult threespine sticklebacks died before trapping and were removed when found. Trapping did not completely remove all of the fish because additional threespine stickleback juveniles were caught in 2003.

Maximum and minimum water temperatures in the mesocosms were recorded every two weeks and ranged from 8 to 34 C during the study. Temperature changes between day and night were enough to keep the mesocosms from permanently stratifying. Diurnal stratification did develop in the mesocosms, especially on hot summer afternoons, but cool nights resulted in homogeneous temperatures and DO concentrations early in the morning. To simulate wave action and mixing on the surface of the reservoirs and to ensure dissolved oxygen (DO) concentrations remain high enough for fish, small aquarium air stones (4 cm-length x 1.3 cm width) were placed five cm under the water surface on the same day that the fish were added. On September 4, 2002 a kink in the air line to one of the short tanks was observed. Without aeration, DO concentrations dropped to 4.6 mg/L. After the kink was removed, DO concentrations returned to nearly saturated concentrations. Otherwise, the lowest DO concentration observed in the mesocosms was 5.7 mg/L and occurred before the aeration stones were installed. With aeration, DO concentrations remained close to or above saturation. The size and placement of the air stones were such that approximately the top 20 cm of water were mixed but mixed gently enough so not to disturb the sediment/water interface which was about 140 and 290 cm below the surface in the shallow and deep mesocosms, respectively. Low turbidity measurements through April and May show that the sediment was not stirred when the airstones were installed on May1, 2002 (Figure 3.2). As mentioned, the jump in turbidity following draining was probably due to the loss of head pressure and the observed gas bubbles escaping from the peat soil. Diurnal temperature stratification was less obvious after installation of the air stones but was still observed on hot afternoons.

Water samples were taken from a depth of 0.3 m from each mesocosm every two weeks using a Van Dorn sampler. Samples were analyzed using standard methods by the Department of Water Resources Bryte Analytical Laboratory (http://wq.water.ca.gov/bryte/) for the following water quality parameters: Total Organic Carbon by combustion (TOC), Dissolved Organic Carbon by combustion (DOC), UV Absorbance at 254nm (UV254), Turbidity, pH, Total Mercury, Total Kjeldahl Nitrogen (TKN), Dissolved Ammonia, Dissolved Nitrite and Nitrate, Total phosphorus and Ortho-phosphate. In addition to these water quality measures, the following field data were collected at the time of sampling: Temperature, Dissolved Oxygen (DO) and Secchi Depth. Sub-samples of juvenile fish trapped in 2002 were analyzed for whole fish total mercury concentrations by the California Department of Fish and Game Water Pollution Control Laboratory in Rancho Cordova, California. These analyzed fish hatched in the mesocosms, were observed as fry and were later trapped and analyzed at a juvenile length of approximately two to three cm.

Salinity in the mesocosms was not monitored in 2002. However, at the end of the study, specific conductance (SC) was 194 uS/cm in the deep mesocosms and 243 uS/cm in the shallow mesocosms. Specific conductance in the Sacramento River at West Sacramento ranges from 124 to 241 uS/cm, and is 161 uS/cm on average (DWR 2003). During the study period, March through December 2002, evaporation less precipitation was approximately 50 cm in the mesocosms. The water lost to evaporation was replaced with Sacramento River water collected from the same West Sacramento location. In the deep mesocosms which contain approximately 290 cm of water, this 50 cm of water loss is about 18% of the volume. Specific conductance of the water used to fill the mesocosms in early 2003 was about 170 uS/cm. Assuming a starting SC of 170 uS/cm, an 18% increase in SC would have resulted in an increase of SC from about 170 to 201 uS/cm, consistent with the measured SC at the end of the study which ranged from 180 to 204 uS/cm in the four mesocosms. Similarly in the shallow mesocosms which contain slightly less than half the water volume as the deep mesocosms, a 36% increase in SC would have resulted in an increase of SC from about 170 to 231 uS/cm, consistent with the measured SC at the end of the study which ranged from 234 to 257 uS/cm in the four mesocosms. Other factors that could have affected salinity include the potential release of salt from the soil and the fact that precipitation fell in the mesocosms not just when they were full but also when they were drained to a depth of one foot which would increase dilution of salts. Nevertheless, increases in salinity were consistent with what would be expected from evaporation and dramatic changes in salinity were not apparent.

3.3 Results and Discussion

Using mesocosms or physical models of the proposed reservoir islands allowed for a better understanding of some ecological processes that will influence project operations and be influenced by operations. Phytoplankton biomass at the time of reservoir release was lower than expected considering that nutrient rich agricultural peat soils were flooded. Further understanding of the mechanisms likely to control phytoplankton dynamics and the development of predictive models for the proposed reservoirs will require additional small, medium and large scale studies. Nutrient concentrations in the mesocosms are presented in Figures 3.4 through 3.8. Chlorophyll *a* and pheophytin *a* concentrations are presented in Figures 3.9 and 3.10, respectively. Zooplankton developed visible clusters in the clear-brown water of the mesocosms and may have controlled algal populations, but again many additional studies are needed, on many scales, to flesh out all the complex and interacting ecological processes controlling the processes of phytoplankton dynamics and their effects on the process of OC loading. Another factor, among many, that may be in part responsible for lower than expected phytoplankton contributions to OC concentrations could be a negative interaction between DOC and phytoplankton (Carpenter et al. 1998). Plate 3.4 shows a sample of the clear-brown, DOC rich, water in the mesocosms.

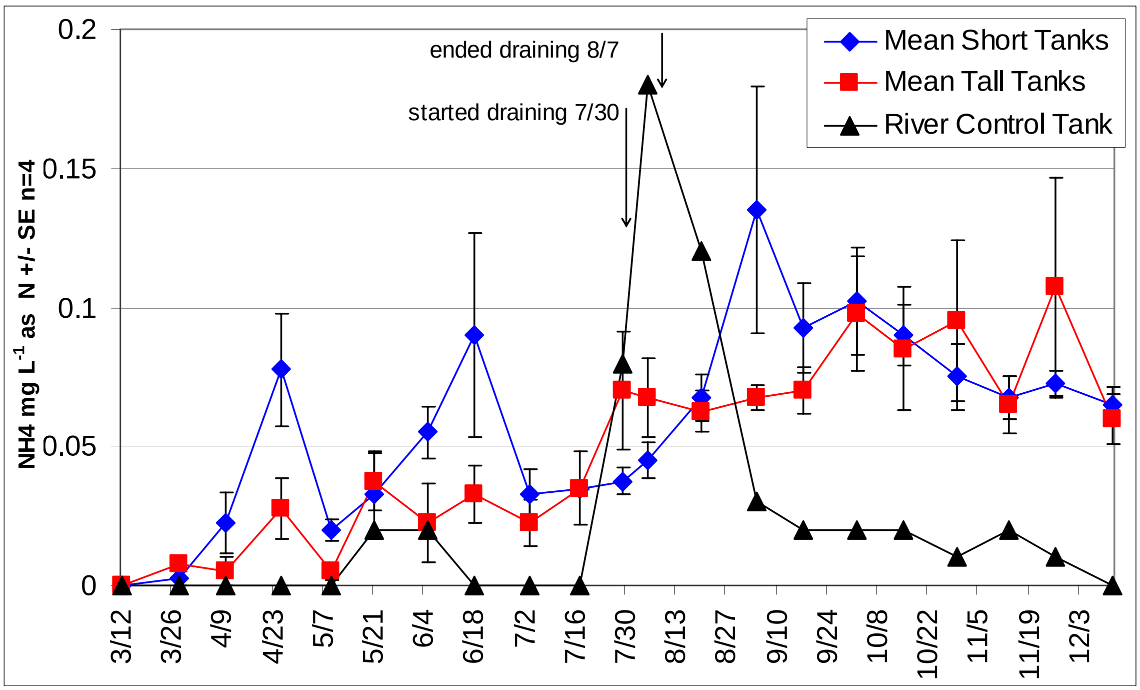


Figure 3.4: Mean Dissolved Ammonia in Mesocosms

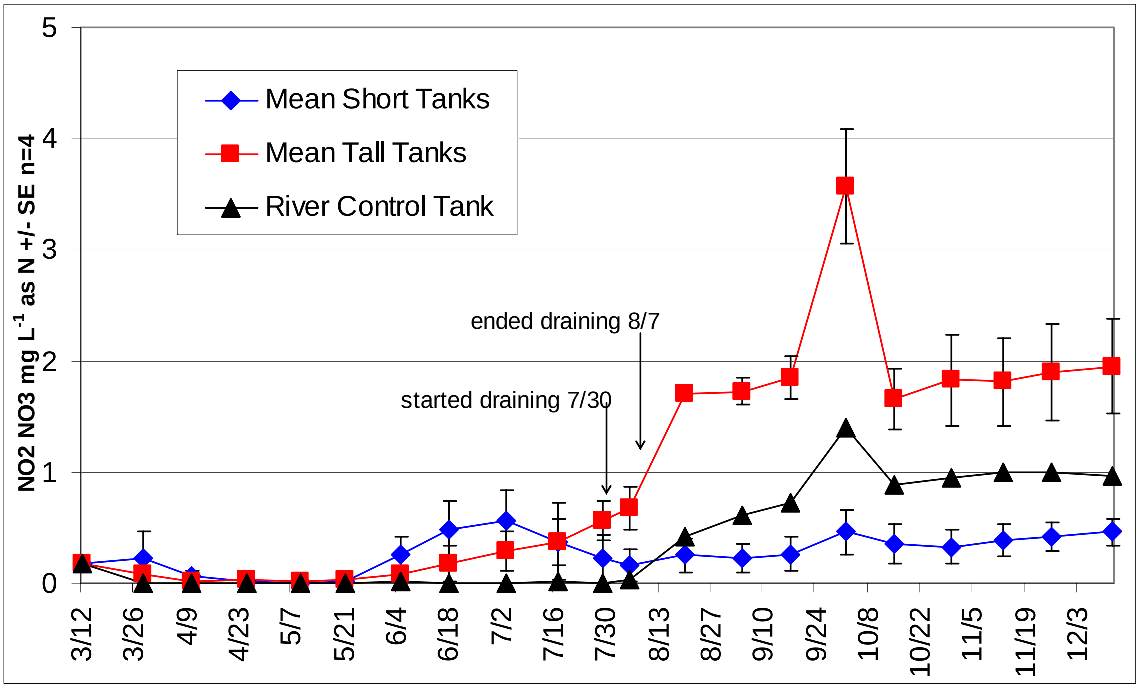


Figure 3.5: Mean Dissolved Nitrite and Nitrate in Mesocosms

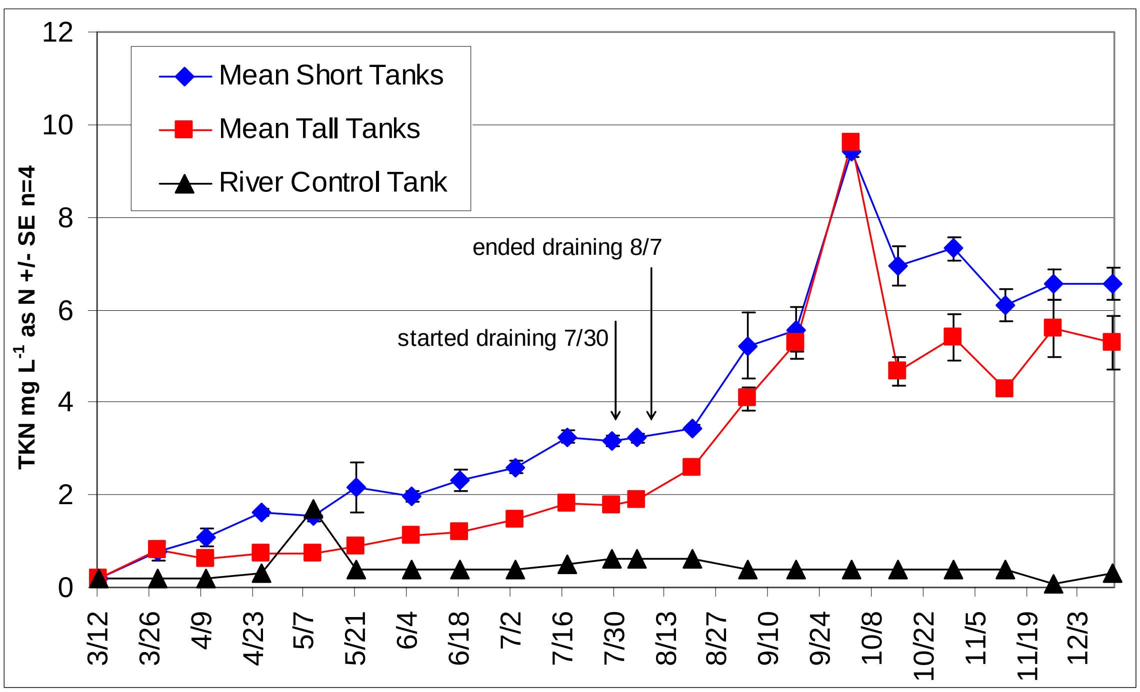


Figure 3.6: Mean TKN in Mesocosms

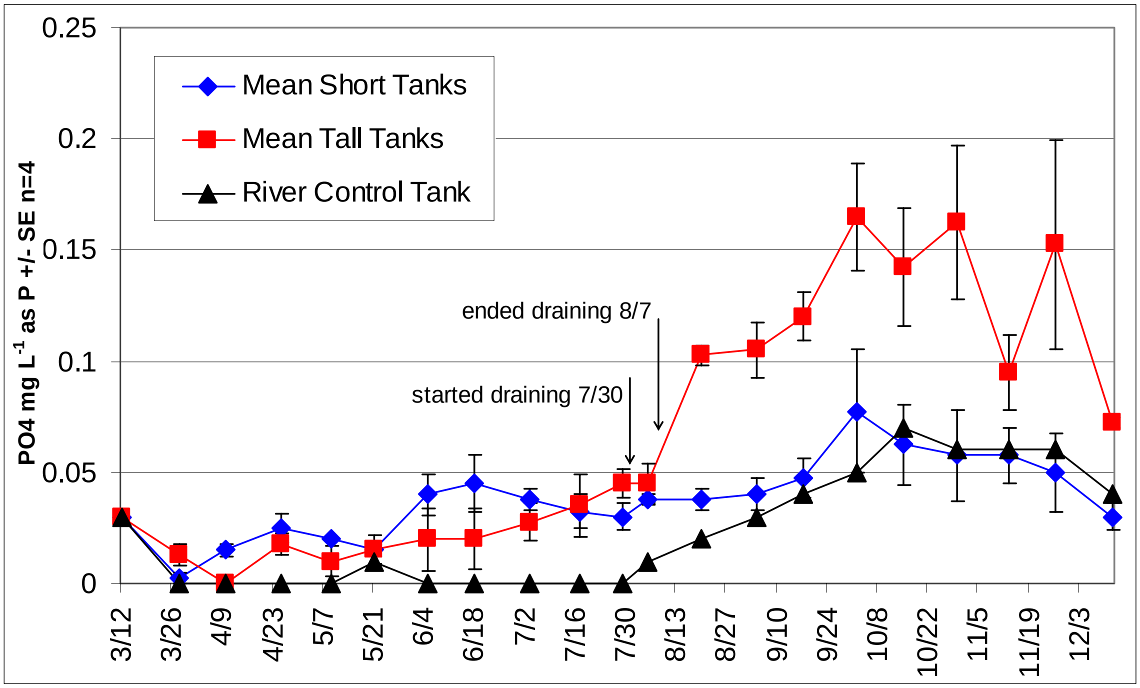


Figure 3.7: Mean Dissolved Orthophosphate in Mesocosms

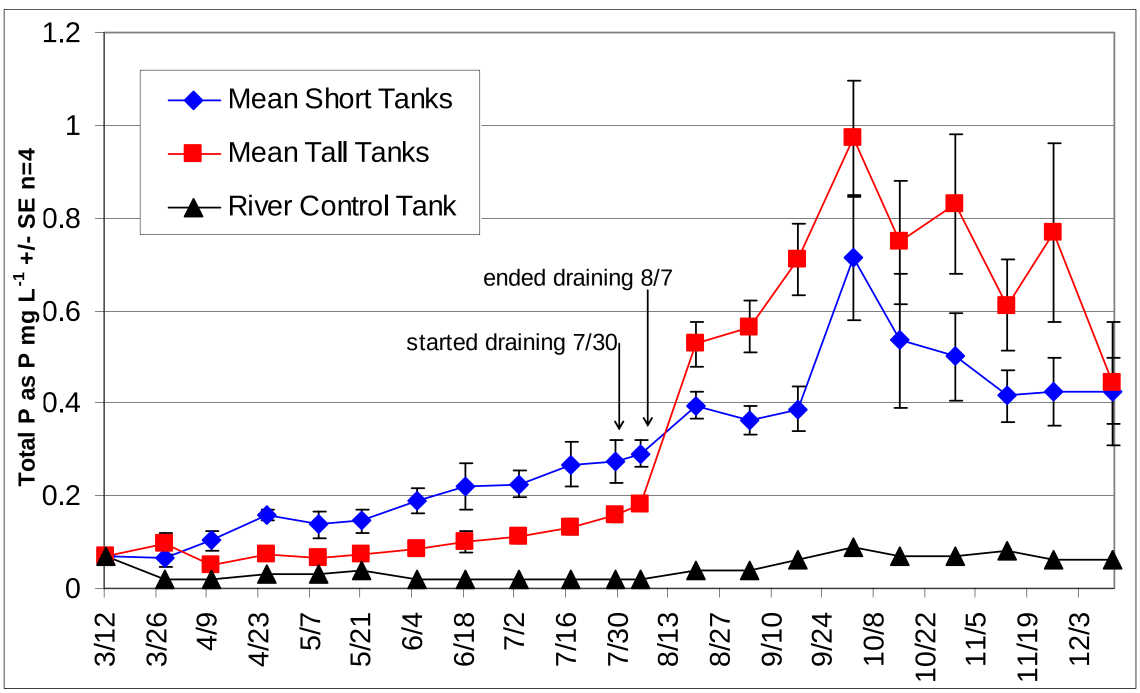


Figure 3.8: Mean Total Phosphorus in Mesocosms

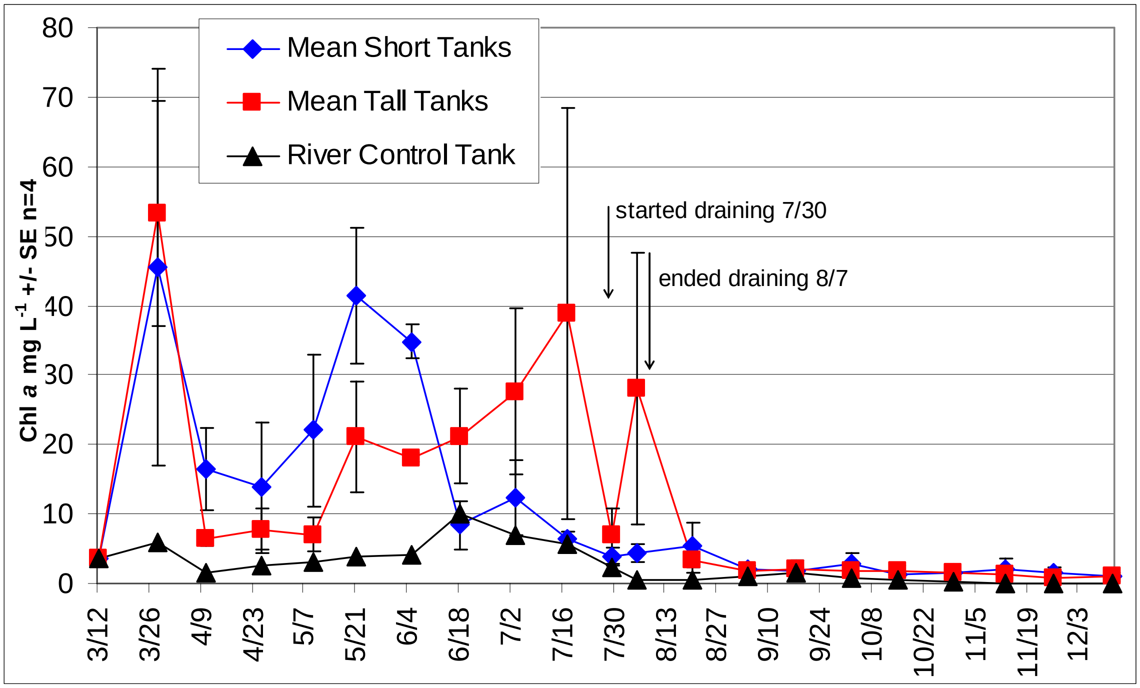


Figure 3.9: Mean Chlorophyll a Concentrations in Mesocosms

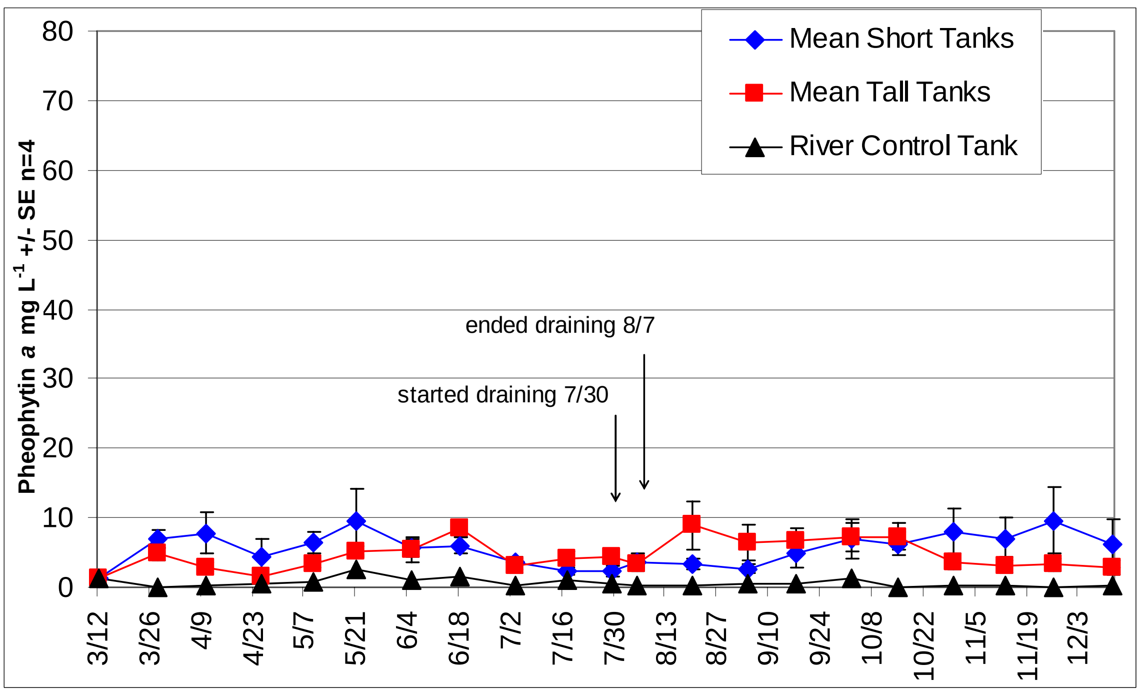


Figure 3.10: Mean Pheophytin a Concentrations in Mesocosms

Plate 3.4: Sample of Mesocosm Water in the Van Dorn Sampler

While Egeria appears to have increased OC loading rates, especially after the mesocosms were drained, differences between loading rates in the deep versus shallow mesocosms (Figures 3.14 trough 3.17) were not dramatic like the observed differences were between submersed macrophyte biomass. After draining, there was zero biomass observed in the deep mesocosms while dense beds of plants filled the shallow mesocosms (Plates 3.5 and 3.6). The plants were not destructively sampled for quantitative biomass measurements but there was so much *Egeria* that grew in the shallow mesocosms that terrestrial grass plant was able to get a root-hold and grow out of one of the shallow mesocosms (Plate 3.5). Similar loading rates between shallow and deep mesocosms despite dramatic differences in *Egeria* biomass (Figures 3.14 trough 3.17) suggest that peat soil is the overwhelming source of OC loading.

Figures 3.11 through 3.13 show the mean TOC, DOC and POC concentrations in the mesocosms during the study. The TOC loading rates presented in Figures 3.14 through 3.17 were calculated by standardizing the rate of TOC concentration increase over time to a one meter water depth by multiplying by the water depth in the mesocosms. This calculation removed the effect of dilution by depth and produced aerial loading rates. DOC loading rates (not shown) calculated the same way were almost identical to those calculated from TOC concentrations. The low concentrations of POC shown in Figure 3.13 were indirect measures, calculated as the difference between TOC and DOC. Nevertheless, chlorophyll *a* and pheophytin *a* concentrations were also low relative to the high OC concentrations in the water and further suggest that the peat soil was the dominant source of OC loading in the mesocosms. Observations from 2003 suggest that *Egeria* biomass is increasing relative to 2002 and results may show that biological productivity has a larger contribution to OC loading in years following initial flooding. DOC has been extracted from water from the both shallow and deep mesocosms for carbon dating and should be another indirect tool for comparing loading from peat vs. primary productivity. Results from the carbon dating are expected soon.

Plate 3.5: Inside one of the Shallow Mesocosms after draining
(Note the dense bed of *Egeria* and the grass growing at the surface of the water (not in the soil) supported by the Egeria)

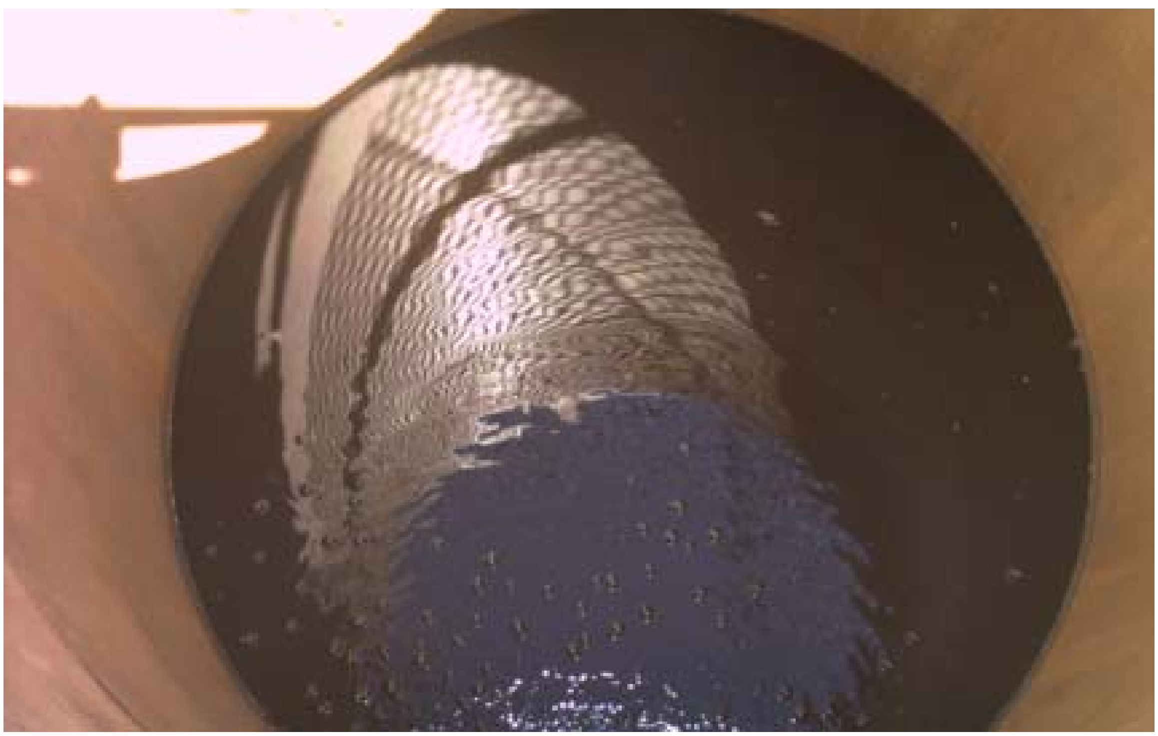


Plate 3.6: Inside of a Deep Mesocosm after Draining to a Depth of 0.3 m

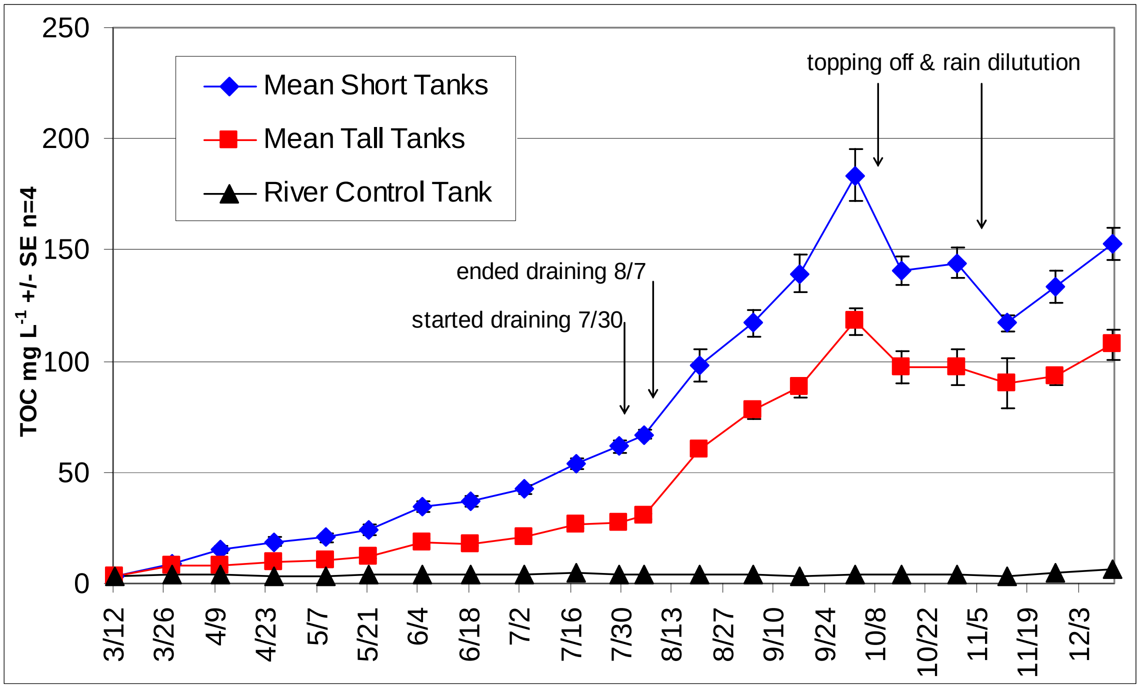


Figure 3.11: Mean TOC Concentrations in the Mesocosms

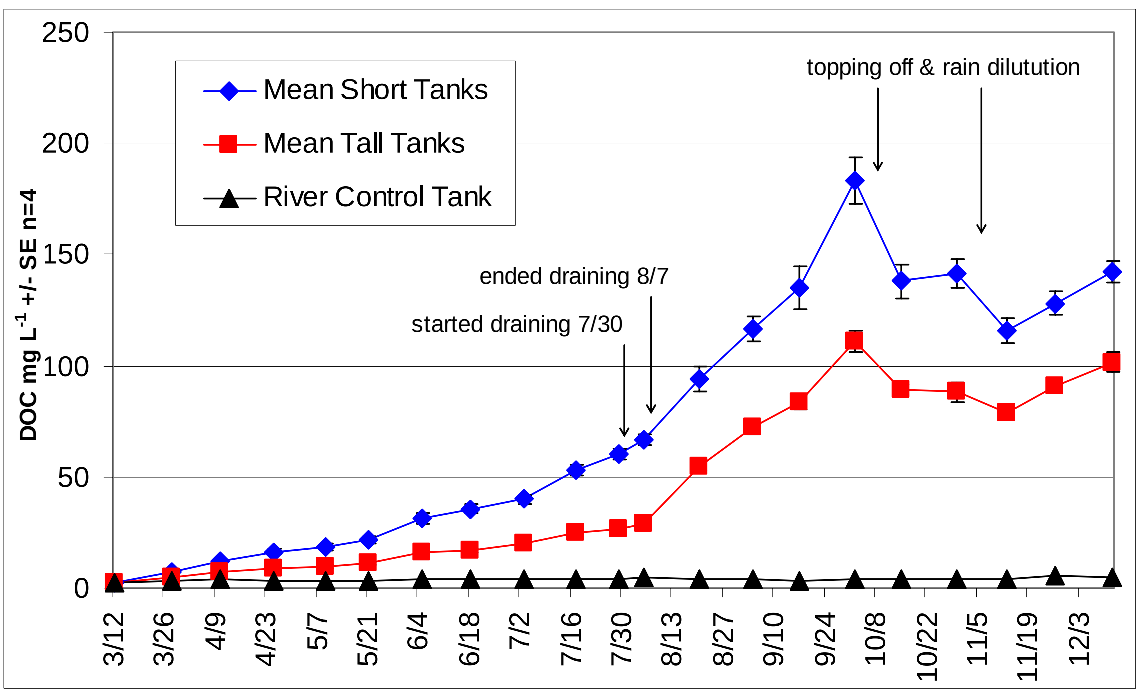


Figure 3.12: Mean DOC Concentrations in Mesocosms

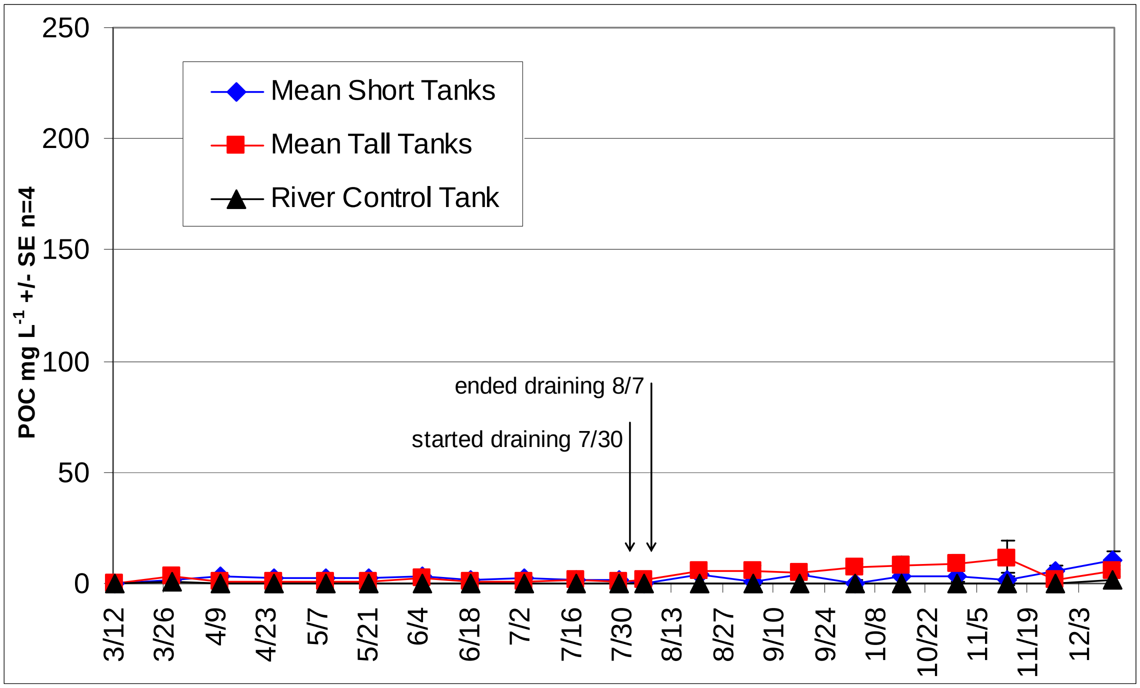


Figure 3.13: Mean POC Concentrations in Mesocosms

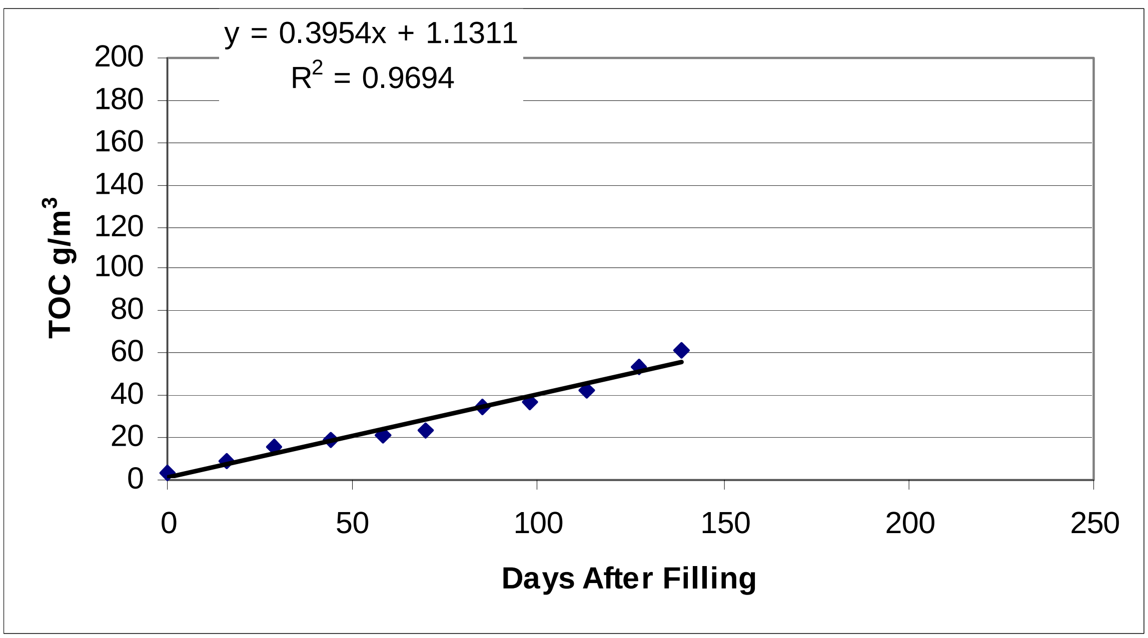


Figure 3.14: Total Organic Carbon in full Shallow, 1.4 m, Mesocosms
(Note: Standardized for 1 meter, m*1.4 = 0.554 gC/m2/d.)

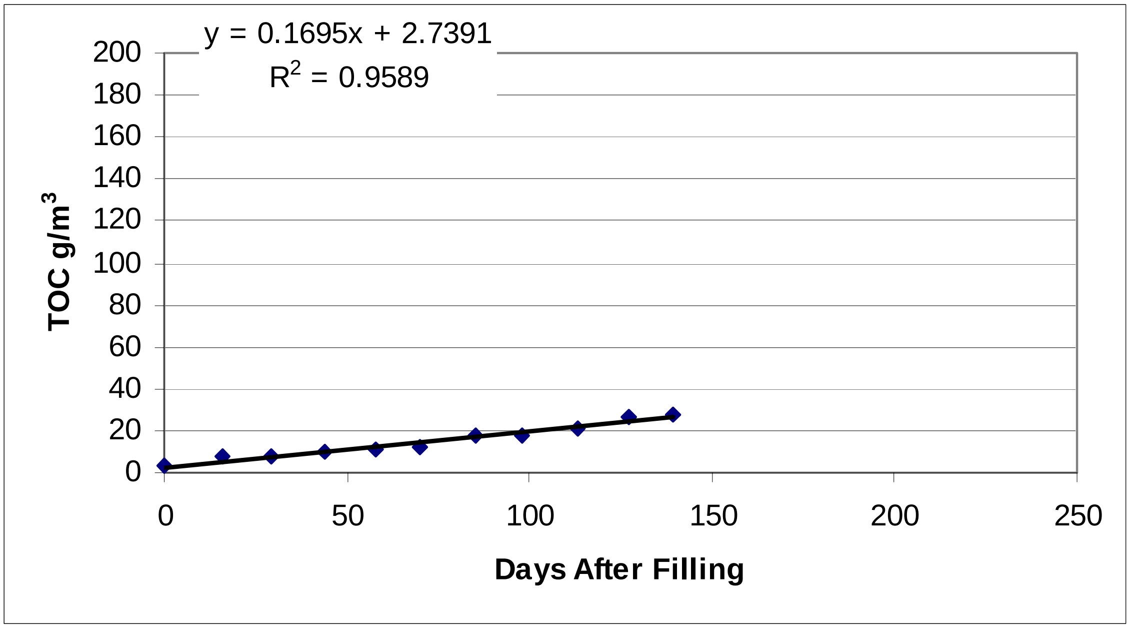


Figure 3.15: Total Organic Carbon in Full Deep, 2.9 m, Mesocosms
(Note: Standardized for 1 meter, m*2.9 = 0.492 gC/m2/d)

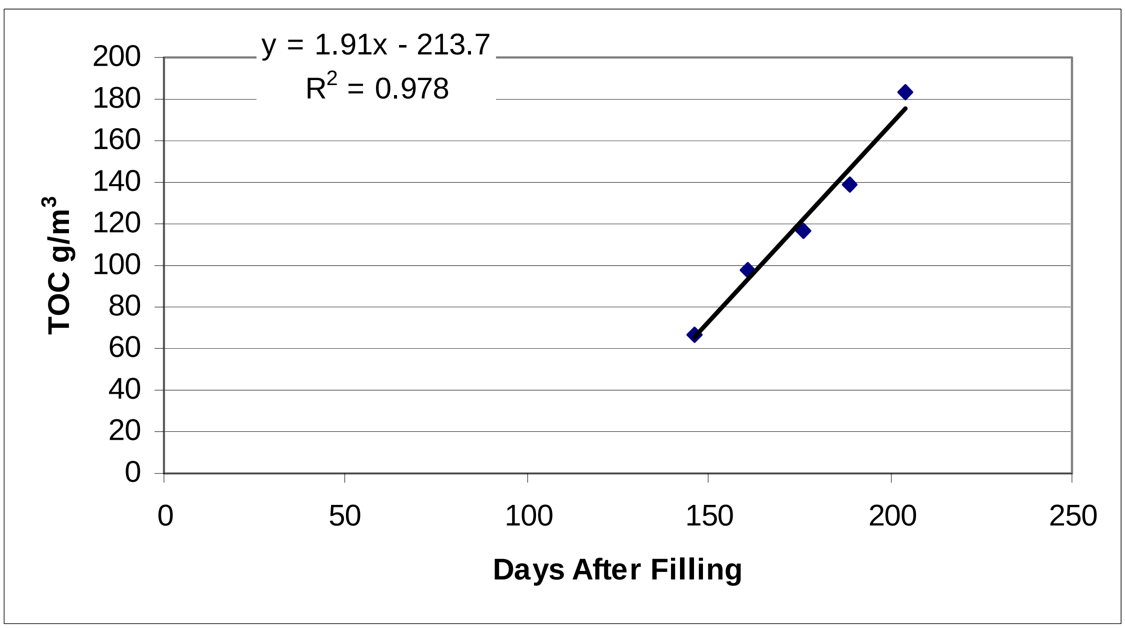


Figure 3.16a: Total Organic Carbon in drained shallow, 0.3 m, Mesocosms
(Note: Standardized for 1 meter, m*0.3 = 0.573 gC/m2/d)

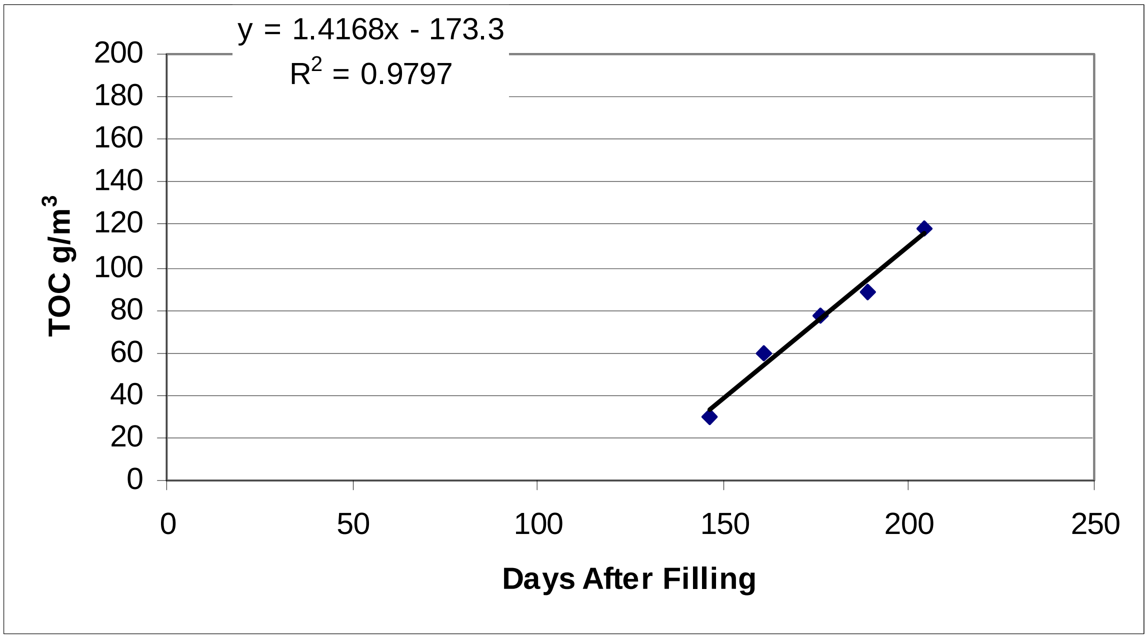


Figure 3.16b: Total Organic Carbon in Drained Deep, 0.3 m, Mesocosms
(Note: Standardized for 1 meter, m*0.3 = 0.425 gC/m2/d)

Rain falling in the mesocosms (Figure 3.3) from November 7th through November 10th had a noticeable dilution effect on water quality in the drained mesocosms (Figures 3.11 and 3.12). A similar amount of rain fell in May but had a minor if noticeable effect on water quality because the mesocosms were full then. The November rain was about 10% of the volume of the drained mesocosms but in May when mesocosms were full this amount of rain was only about 1 % of the volume of the water in the full mesocosms. Similarly, dilution effects from topping off the mesocosms to make up for evaporation losses are obvious when the mesocosms were drained to a depth on 0.3 m but not apparent when the mesocosms were full.

Mean total mercury (Hg) concentrations in fish from the mesocosms were 0.03 ug/g (ppm) for threespine stickleback samples and 0.01 ug/g for *Gambusia* samples collected from the mesocosms. The detection limit was 0.01 ug/g. All the fish analyzed were born and reared in the mesocosms and were approximately three months old when collected. Total Hg analyses of mesocosm water never resulted in detection of Hg but the detection limit was 0.2 ug/L. This detection limit is probably an order of magnitude above the concentrations at which methylmercury dynamics operate in the Delta.

The treatment variable in this study was water depth. Varying water depth and hence the light available for submersed macrophyte growth facilitated the identification of the effects of submersed macrophytes on the process of organic carbon loading. The mechanism controlling macrophytes and their effects on water quality was light attenuation. Submersed macrophytes were not destructively harvested in this study because it is a multiple year study. Nevertheless qualitative and quantitative descriptions of the *Egeria* productivity are possible. Approximately 100% of the surface area of the shallow mesocosms became covered with *Egeria* by the end of July when the mesocosms were drained to simulate reservoir discharge while 0% or no *Egeria* was observed in the deep mesocosms before or after draining (Plates 3.5 and 3.6, respectively).

Published data on the standing biomass of submersed vegetation vary widely because of inconsistencies in excluding or including underground organs, epiphytic algae and inorganic matter. However a reasonable range for estimates of submersed macrophyte biomass for species such as *Ceratophyllum demersum, Potamogeton pectinatus* is about 100 g d.w. m^{-2} to 1000 g d.w. m^{-2} (Sculthorpe 1967). In the spring and early summer of 1996, Anderson et al. 1996 measured *Egeria* in Sandmound Slough and Seven Mile Slough by physically removing *Egeria* from under a quadrant. Their measurements were about, 1800 g d.w. m^{-2} and 2100 g d.w. m^{-2} respectively, and suggest that *Egeria* biomass in the Delta is at the upper end or above Sculthorpe's range. Filamentous algae and periphyton growing intertwined in the plant beds and on the plants can result in higher biomass estimates however. By early August 2002 when the mesocosms were drained, *Egeria* biomass was probably around 200 to 300 g d.w. m^{-2}.

Higher OC loading rates were observed in the mesocosms with *Egeria* but a linear relationship between DOC and TTHMFP (Figure 3.17) suggests that peat soil and not primary productivity was the overwhelming, or effectively the single source, of OC. A linear relationship between DOC and THMFP has been related to a single source of OC because OC from vegetation has two to five times higher THM reactivity than other sources of OC, such as peat, in reservoirs (USGS 2001). Changes in formation potential for TTHM, chloroform and bromodichloromethane are shown in Figures 3.18 and 3.19. However, a problem was identified in the data used to generate Figures 3.17 through 3.20. Samples collected before October 15, 2002 were not properly diluted by the analytical lab before dosing with chlorine and at least some THMFP data are suspect (Agee 2003 personal communication). Without proper dilution, all of the chlorine is used up and the THMF maxes out prematurely. A flat spot in the data from August 20 through October 2, 2002 is obvious in Figures 3.18 and 3.19. These data were not used in the DOC and TTHMFP regression (Figure 3.17). Analyses completed before August 20, 2002 appear to be valid because they were in the 'transition zone' where the method might have worked, but were above the prescribed DOC concentration of 10 mg/L and should be considered invalid. Figure 3.21 shows TTHMFP data only for samples collected October 15, 2002 or later when proper dilutions were made by the lab prior to chlorination. Other researchers have identified a problem with the dose-based method for THMFP analysis because results are highly dependent on sample dilution (Fujii et al. 1997). Mean dilutions used by the analytical lab are presented in Figure 3.22.

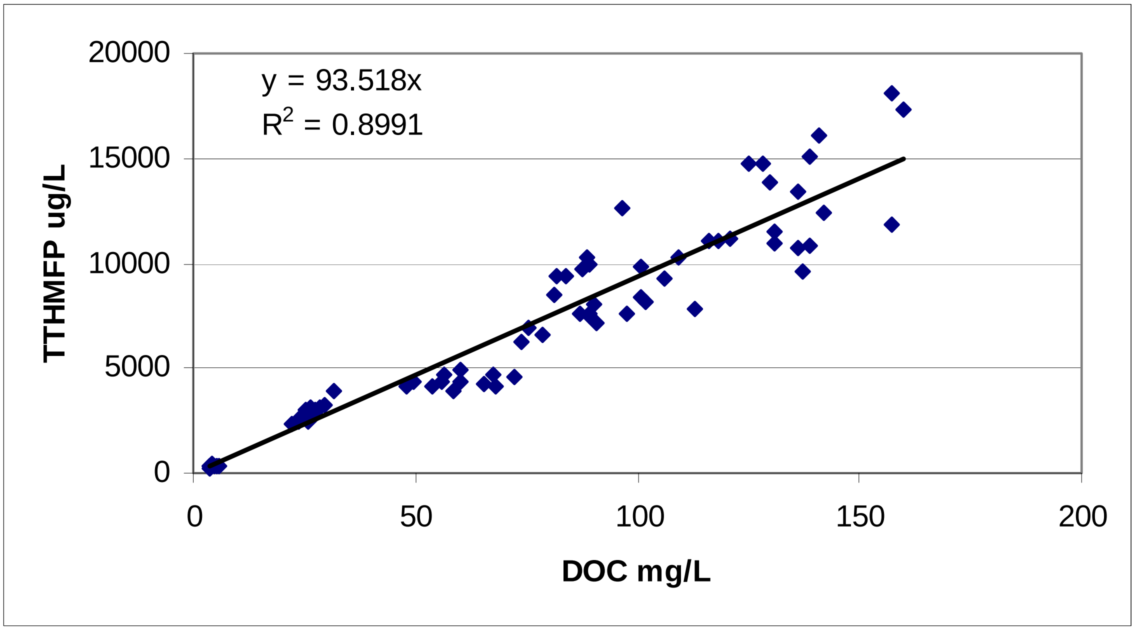


Figure 3.17: Relationship between THMFP and DOC for Mesocosms Water

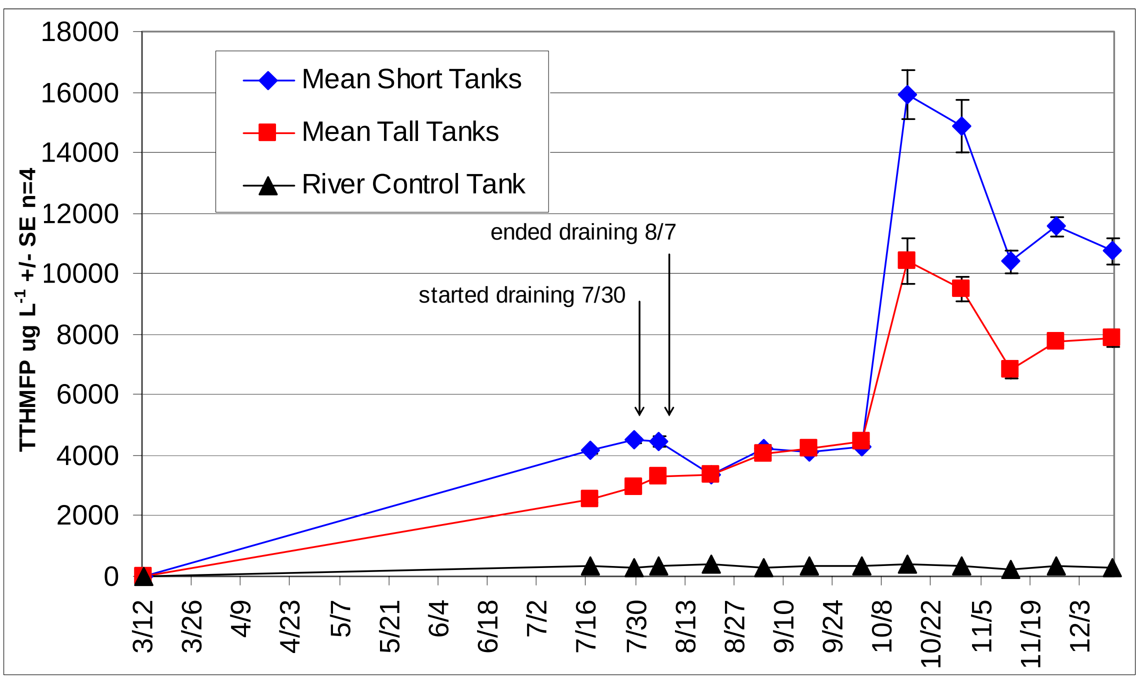


Figure 3.18: TTHMFP for Mesocosm Water

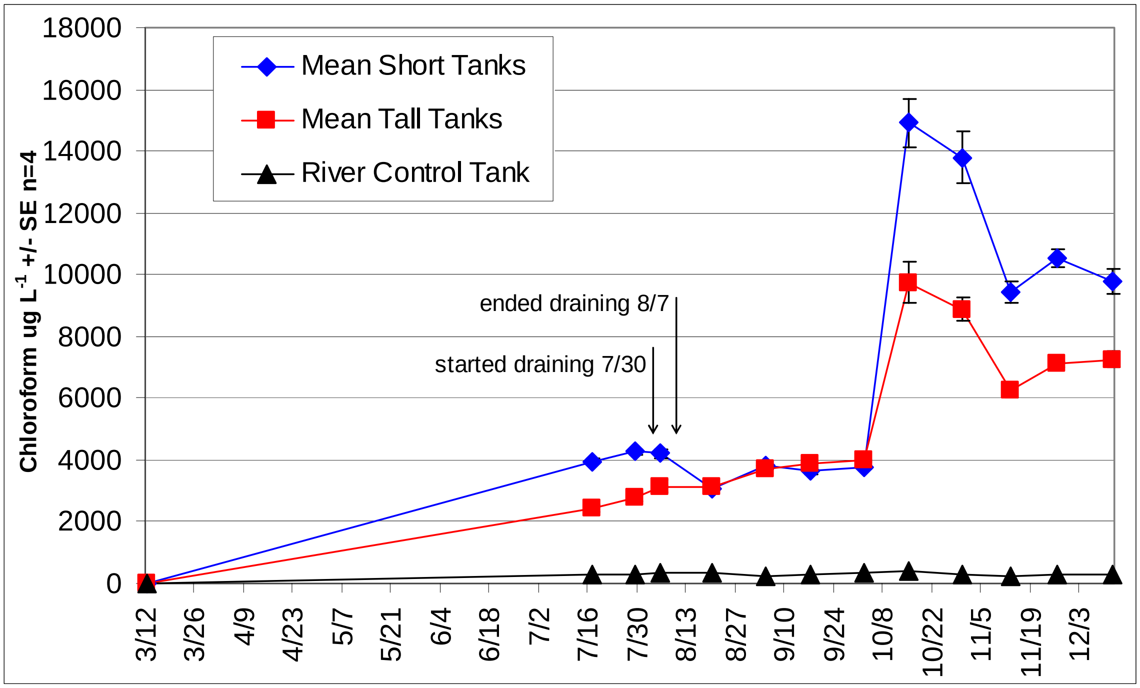


Figure 3.19: Chloroform Formation Potential for Mesocosm Water

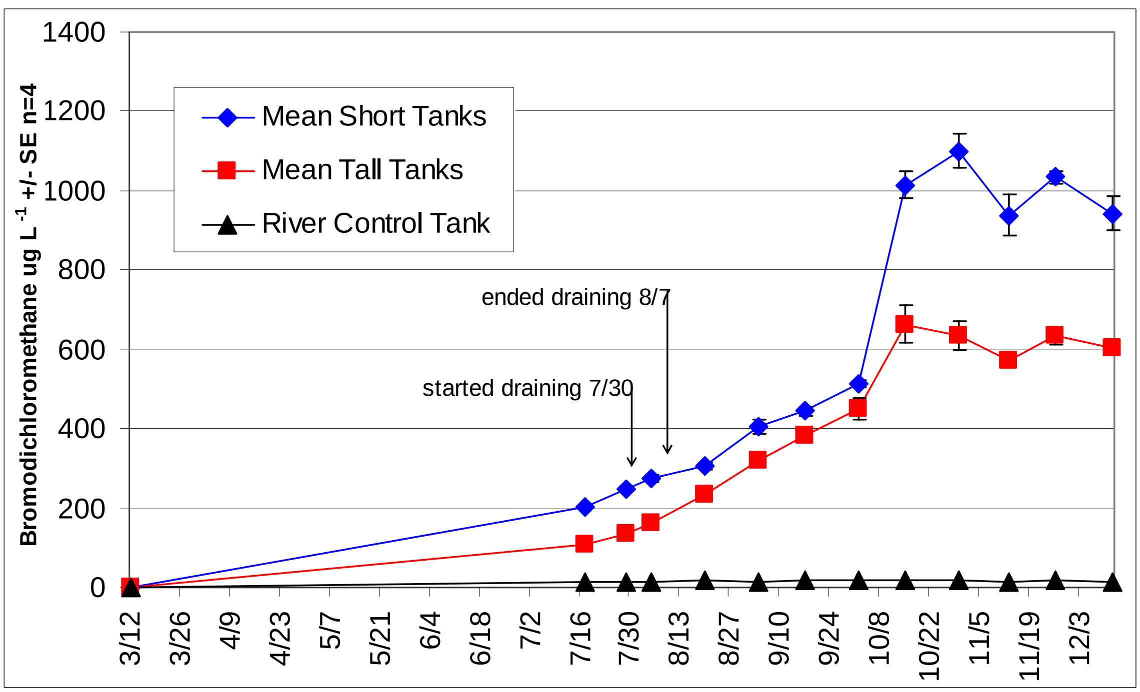


Figure 3.20: Bromodichloromethane Formation Potential for Mesocosm Water

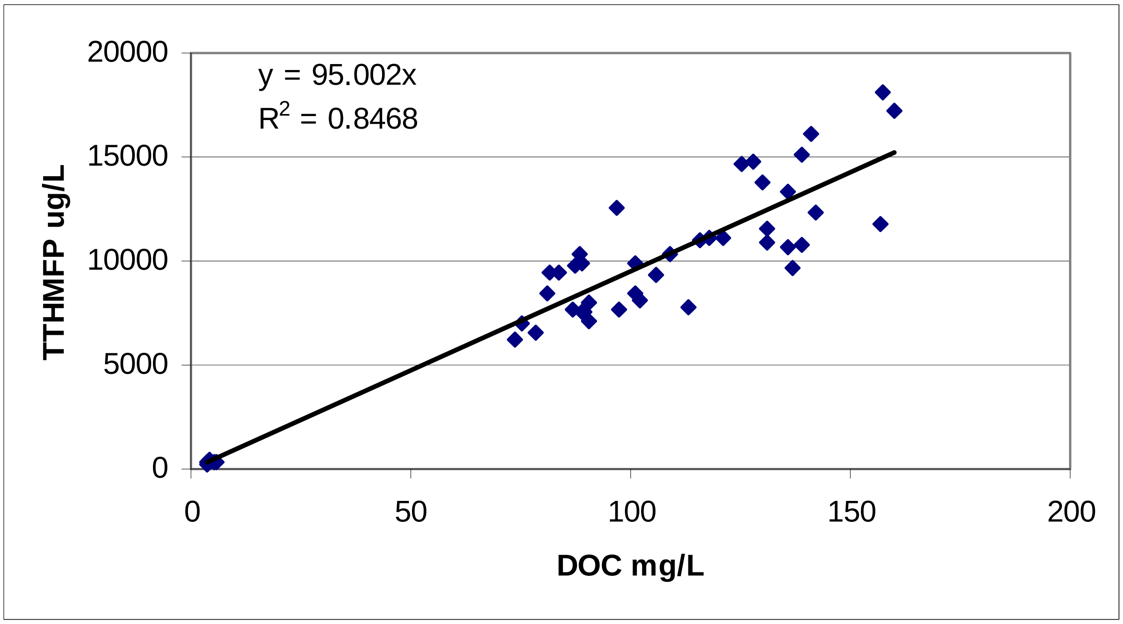


Figure 3.21: Relationship between DOC and TTHMFP
(Note only for samples collected October 15, 2002 or later)

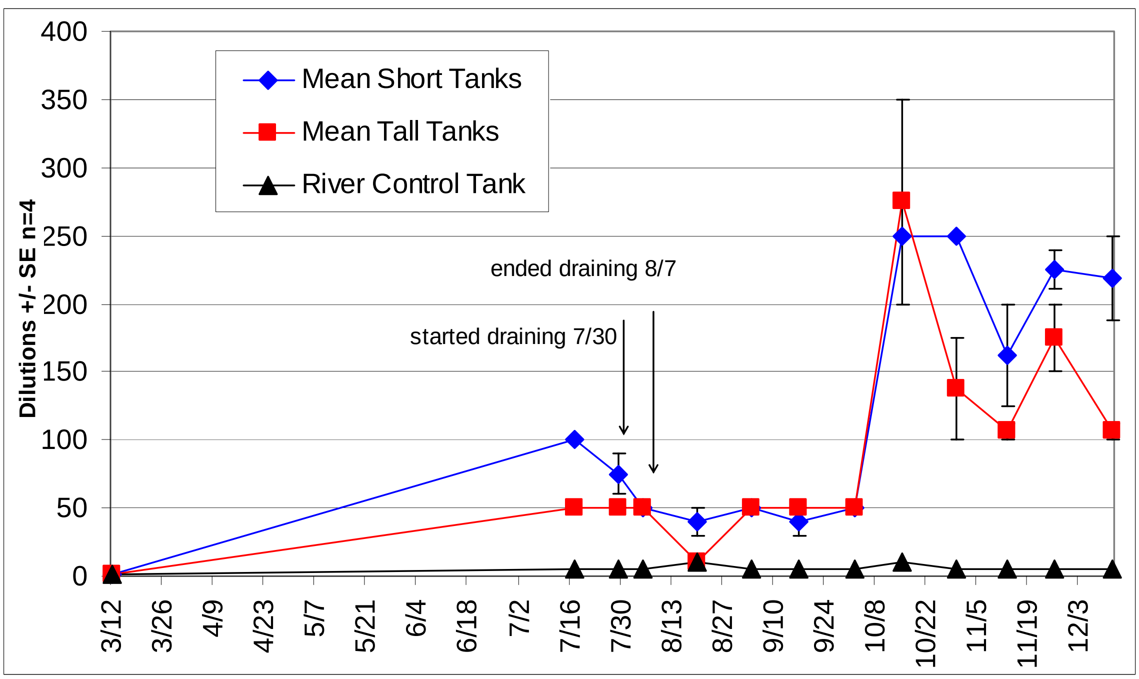


Figure 3:22: Mean Dilutions used in Analyses of THMFP

Despite the problem with the THMFP analysis, the linear relationship between DOC and TTHMFP shown in Figures 3.18 and 3.21 is strong (r^2 = 0.899 and 0.847) and suggests that the peat soil was effectively the single source of OC (USGS 1998). There might be indirect mechanisms that can explain why *Egeria* appeared to increase carbon loading but not result in a non-linear increase in THMFP. The *Egeria* could have facilitated higher peat-derived DOC loading by oxidizing the peat soil near the soil-water interface or otherwise increasing microbial activity or degradation of the peat. Labile *Egeria* exudates or decomposing biomass may have been rapidly metabolized by bacteria and not been a mechanism responsible for higher DOC concentrations in the mesocosms with *Egeria*. Similarly, bacteria may have used phytoplankton exudates and prevented phytoplankton from increasing OC loading relative to the peat soil. Kamjunke et al. (1997) found that phytoplankton exudation, not allochthonous DOC can be the main source of DOC used by bacteria in eutrophic waters. This phytoplankton derived DOC may be easily and rapidly consumed by bacteria and therefore not contribute significantly to overall OC loading relative to peat soil.

Phytoplankton productivity or biomass might also have been limited by the high concentrations of DOC. Carpenter et al. (1998) showed that increasing DOC concentrations substantially reduce chlorophyll concentrations, primary production and their variability. Bioavaliable POC in the Delta is derived primarily from autochthonous phytoplankton production but this production is a small component of the ecosystems mass balance (Sobczak et al. 2002). Phytoplankton-derived DOC is probably an important source of bioavaliable carbon to bacteria in the Delta but may also be ephemeral and in short supply. Therefore, phytoplankton in the mesocosms, in the proposed reservoir islands and in the Delta may not be a significant source of OC loading relative to peat soil. Nutrient supply is another factor that affects phytoplankton dynamics and OC loading. Additional studies are needed to further identify and quantify the complex and interacting sources of OC.

Specific ultraviolet absorbance (SUVA) is calculated by dividing ultraviolet absorbance (UVA) by DOC and provides information about the aromatic structure of DOC in water (USGS 1998). UVA and SUVA results are shown in Figure 3.23 and 3.24, respectively. There was another problem at the analytical lab, this time in the measurement of UVA. During July and early August, samples were not properly diluted before analysis and again resulted in readings that were too low. This problem primarily effected samples from the shallow mesocosms. Only one data point was compromised in the deep mesocosm series. It was possible to interpolate estimates for the bad readings from the relationship between UVA and DOC concentrations (Figure 3.25). The bad data points are shown by the missing UVA and DOC data around 3 abs/cm and mg/L in Figure 3.26. Interpolated estimates were used to create the data points identified by four pointed stars in Figure 3.23. The actual and estimated data were then used to generate the SUVA data shown in Figure 3.24. Mean SUVA values were similar between the deep and shallow mesocosms and remained relatively constant during the study. However, SUVA values were dramatically lower in the river water only mesocosm.

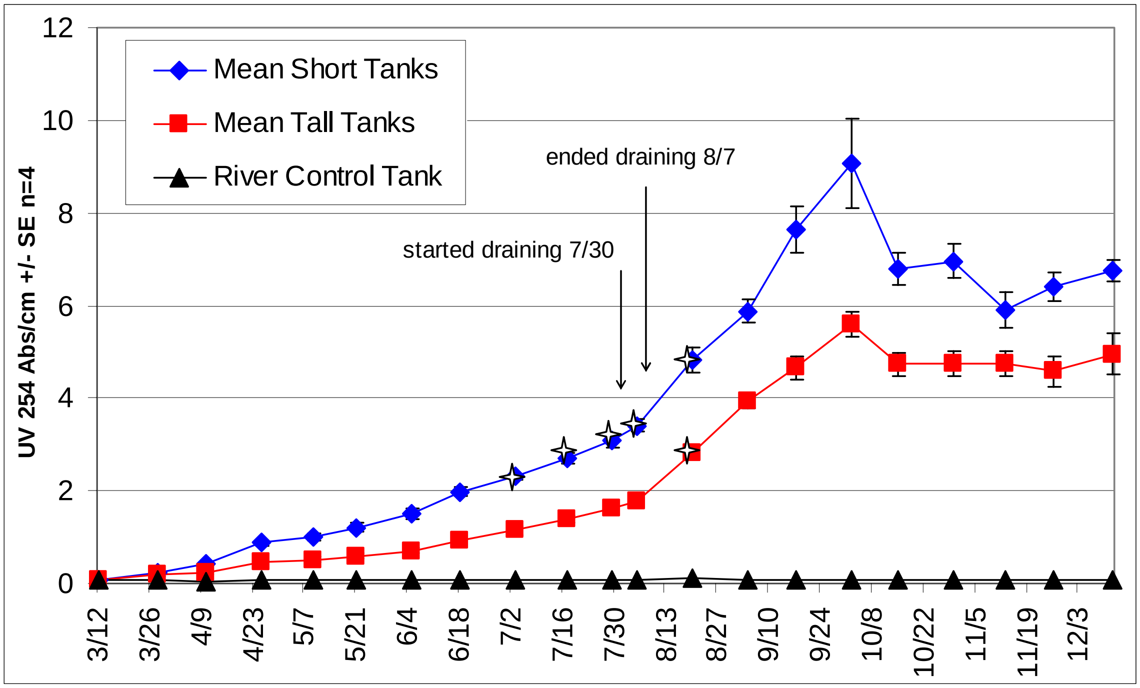


Figure 3.23: UV 254nm Absorbance
(Note estimated data indicated by four-pointed stars)

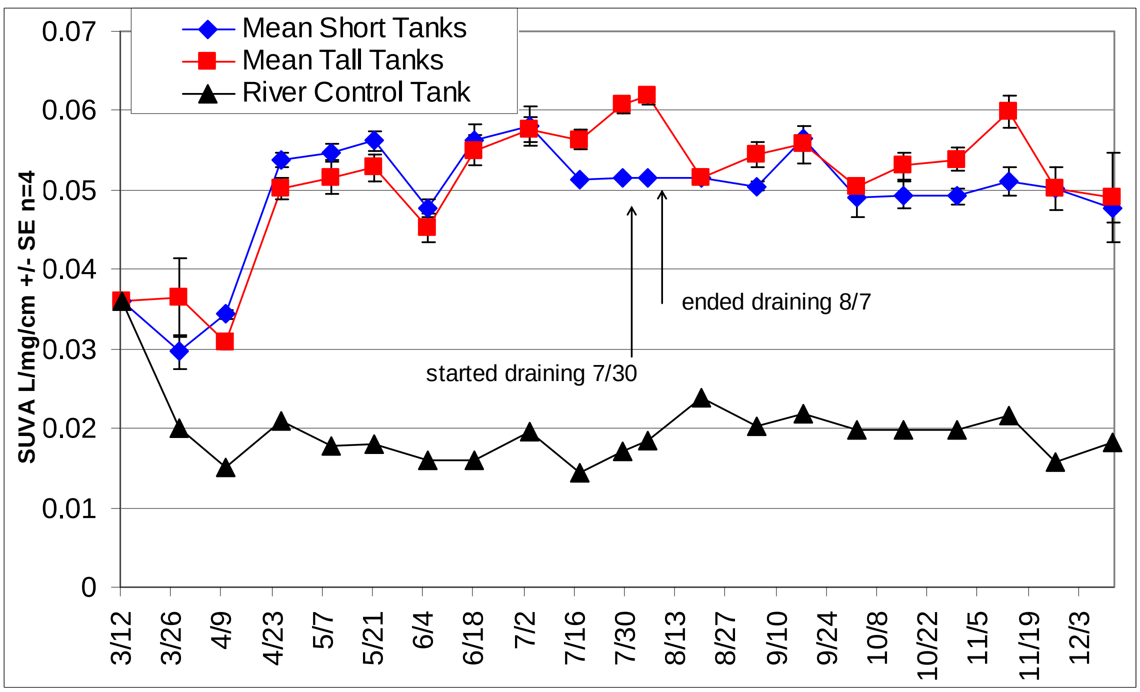


Figure 3.24: Mean Specific UV Absorbance (UVA/DOC)

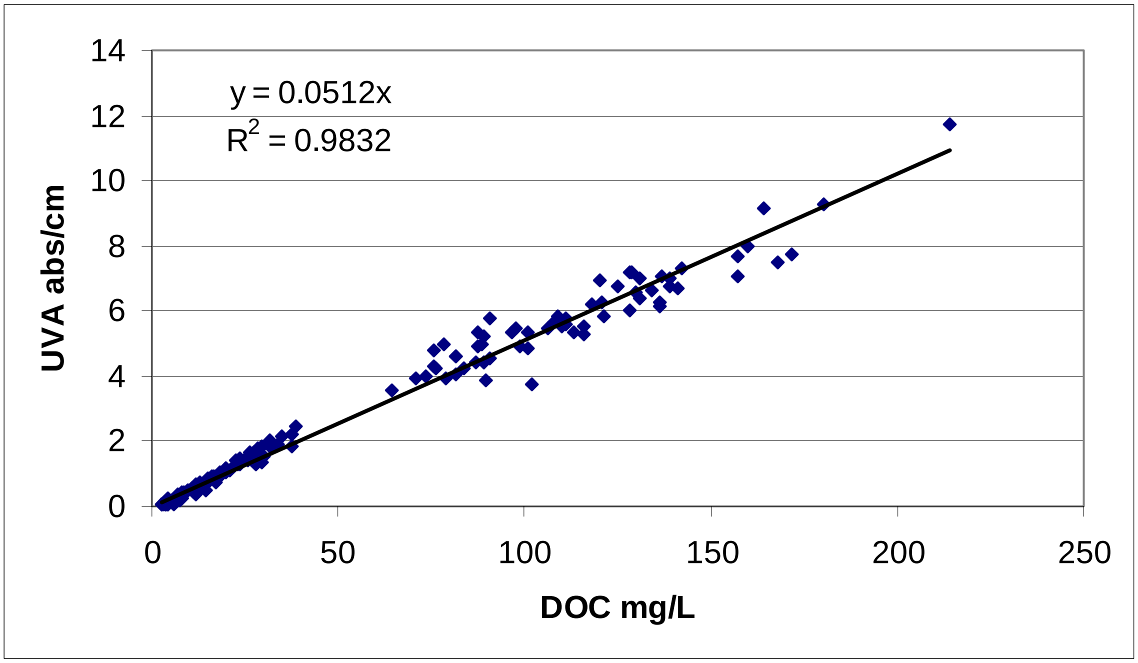


Figure 3.25: Relationship between UVA and DOC for Mesocosm Water

The relationship between UVA and TTHMFP is also linear (Figure 3.26). If the TTHMFP data that were identified as potentially invalid, those data for before October 15, 2002, are removed from Figure 3.27 the relationship stays mostly the same but the r^2 value declines slightly from 0.884 to 0.82 but the linear relationship does not change (Figure 3.27). The strong linear relationships between THMFP and DOC and UVA together with the lack of a linear relationship between SUVA and STTHMFP (Figure 3.29) provide both quantitative and qualitative information about the processes of OC loading that will be important to the in-Delta storage. These relationships suggest that not only was DOC overwhelmingly from a single source, the peat soil, but also that non-aromatic forms of DOC were probably the dominant THM precursors in the water (USGS 1998).

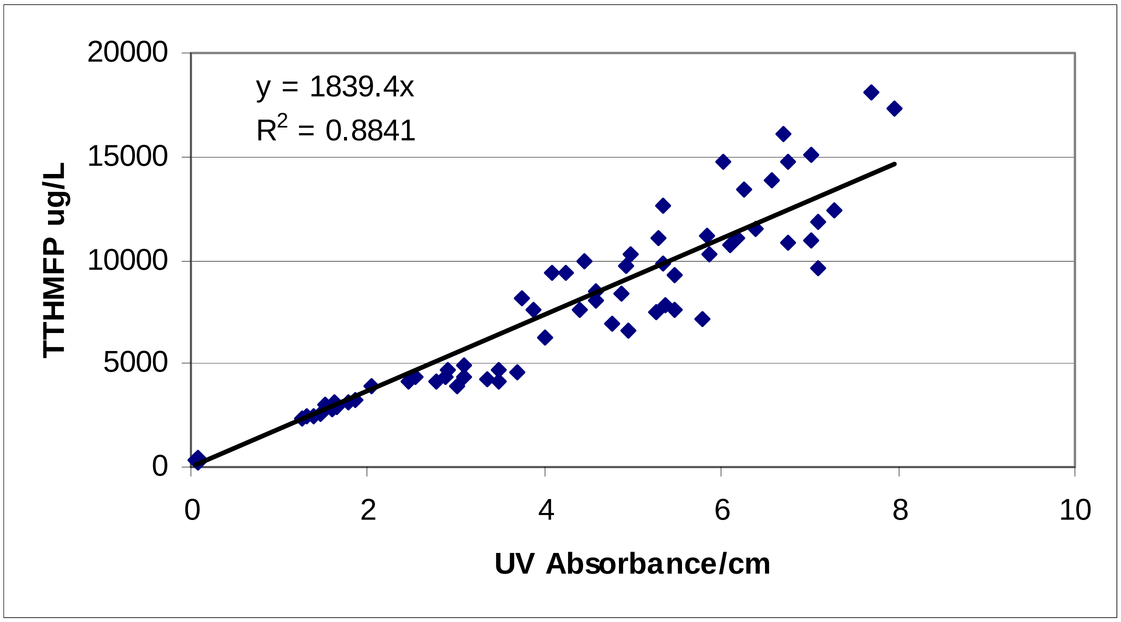


Figure 3.26: Relationship between UV Absorbance and THMFP

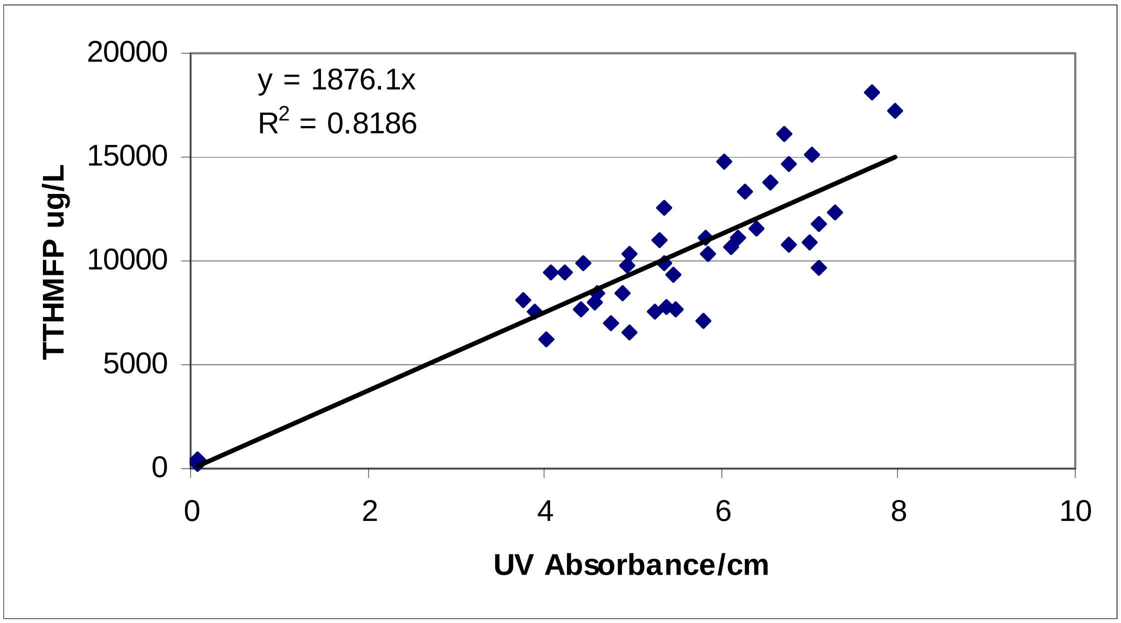


Figure 3.27: Relationship between UV Absorbance and THMFP
(Note: using only data from October 15, 2002 or later)

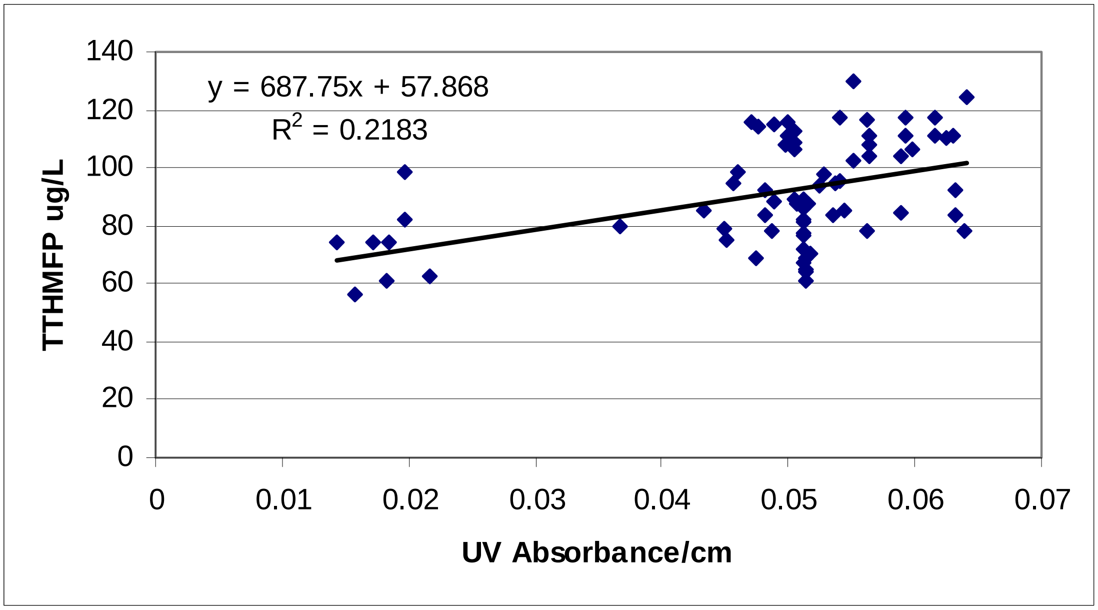


Figure 3.28: Relationship between SUVA and STTHMFP

Preliminary results from the 2003 study suggest that organic carbon loading levels might decline after the first year of flooding. Figure 3.29 is preliminary but shows the same standardized carbon concentrations as shown in Figures 3.14 through 3.17 except here DOC is reported instead of TOC. Again, very little difference was observed between TOC and DOC concentrations in the 2003 study. However, observed *Egeria* and filamentous algae (growing on the *Egeria*) biomass is greater in the second year. THMFP data have not yet been analyzed for the 2003 data but might be higher if *Egeria* and algae contribute significantly to DOC loads in 2003.

In the 2003 study, the new circulation operation for the reservoir islands was simulated in the operation of the mesocosms. Figure 3.29 shows circulation procedures to determine DOC concentrations in the mesocosm water. Declines in DOC are due to dilution from filling (fill) and circulation (circ.) the % indicates the percent of water circulated or exchanged in the mesocosms. For example, if there was one meter of water in a mesocosm and 0.25 meters of water was drained and replaced with Sacramento River water this was a 25% circulation. The tanks were filled in thirds over a three month period. For example if there was 2.1 m head space at the beginning of the study in late January, 0.7 m or 1/3 of the storage capacity was added. Then at the end of February the second third (0.7 m) was added and at the end of March the final third was added and the mesocosms were then full. Figure 3.30 shows relatively flat organic carbon concentrations in the mesocosms because the exchange or circulation rate was approximately in balance with loading rates.

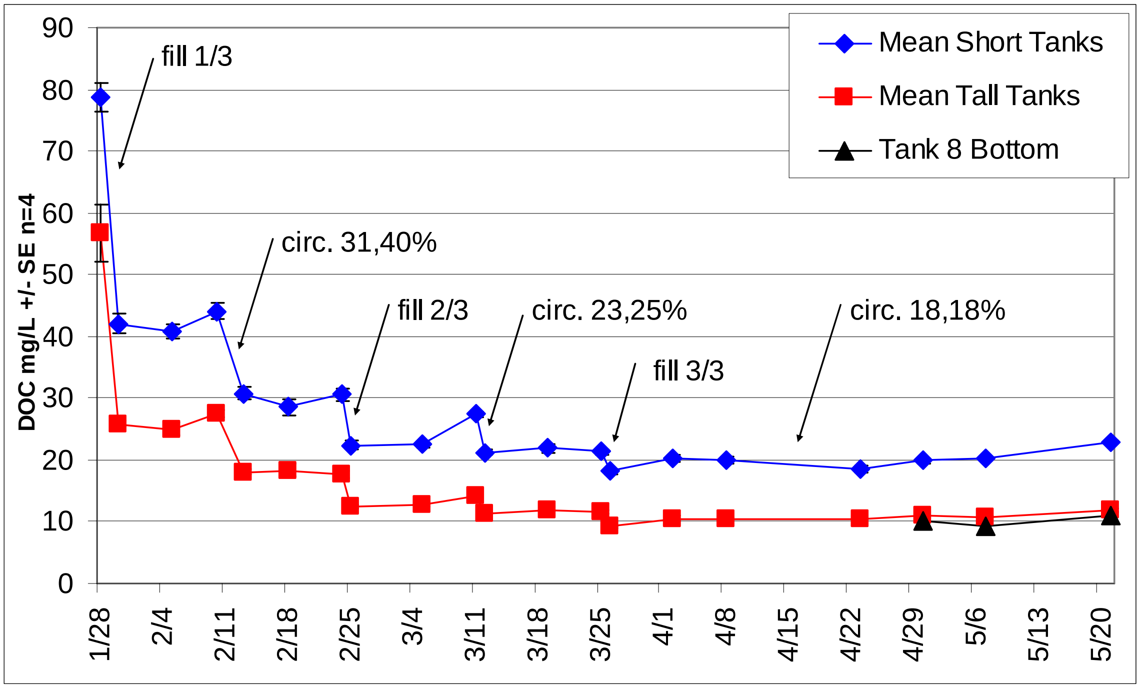


Figure 3.29: Circulation Procedure Mean 2003 DOC Concentrations in Mesocosms

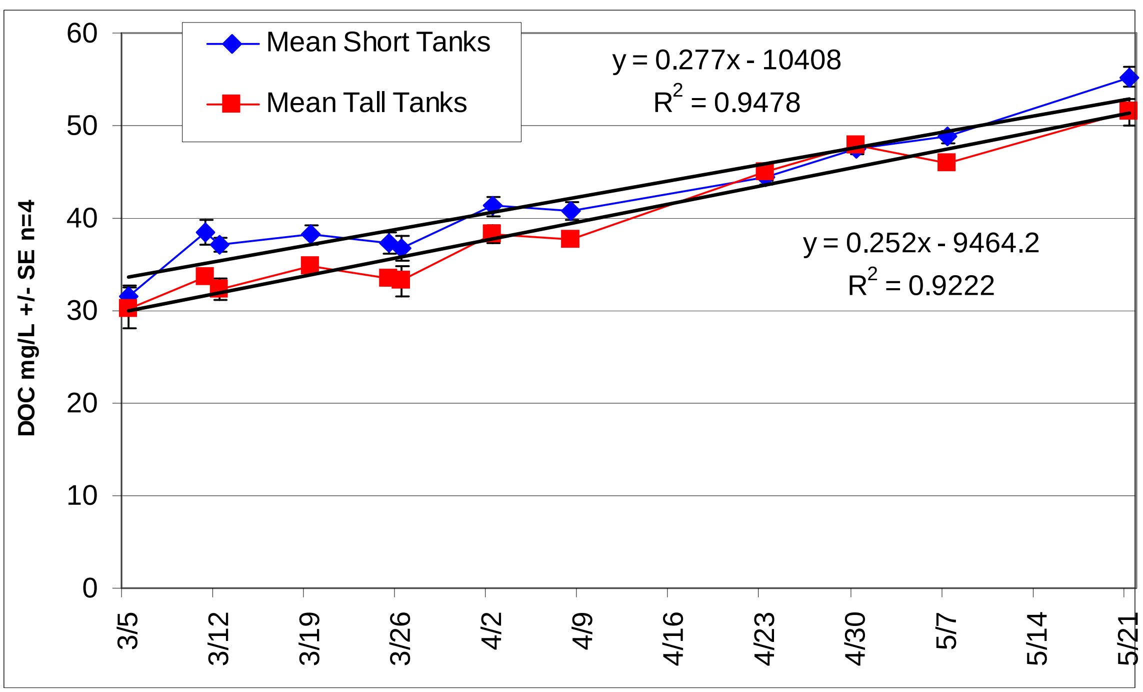


Figure 3.30: Mean 2003 DOC Concentrations in Mesocosms

Predicting organic carbon loading in the proposed in-Delta reservoir islands has been a challenge for over a decade. The first estimates were a part of a 1990 Delta Wetlands Inc. draft EIR (DW 1990), mostly qualitative and based on comparisons to Delta island agricultural drainage. Estimates in this and subsequent EIRs were also limited in that algal and vascular aquatic plant productivity (bioproductivity) was not adequately considered. In recent years, DWR has conducted studies in order to reduce uncertainty and make a recommendation on the project. Much still needs to be done in order to develop process-level, mechanistic models of the reservoirs especially ones that can be used to accurately predict water quality in the reservoirs and at downstream drinking water intakes. Nevertheless, this mesocosm study is the latest step in an ongoing and integrative process to reduce uncertainty.

3.4 References

Carpenter, S.R., J. J. Cole, J.F. Kitchell and M. P. Pace. 1998. Impact of dissolved organic carbon, phosphorus, and grazing on phytoplankton biomass and production in experimental lakes. Limnology and Oceanography 43: 73-80.

California Department of Water Resources. 2002. In-delta storage planning study water quality investigations.

California Department of Water Resources. 2003. The municipal water quality investigations program summary and findings from data collected august 1998 through september 2001.

Jassby, A. D. and J. E. Cloern. 2000. Organic matter sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquatic Conservation: Marine and freshwater Ecosystems. 10: 323-352.

Jones and Stokes. 2000. Delta Wetlands Environmental Impact report/Environmental Impact Statement. California Department of Water Resources. Sacramento, CA.

Kamjunke, N. W. Boing and H. Voigt. 1997. Bacterial and primary production under hypertrophic conditions. Aquatic Microbial Ecology. 13: 29-35.

Mitsch, W. J. and J.G. Gosselink. 1993. Wetlands. Van Nostrand Reinhold, New York. 722 p.

Paterson, M.J., J. W. M. Rudd and V. St. Louis. 1998. Increases in total and methylmercury in zooplankton following flooding of a peatland reservoir. Environmental Science and Technology. 32: 3868-3874.

Sobczak, W. V., J. E. Coern, A. D. Jassby and A. B. Muller-Solger. Bioavailability of organic matter in a highly disturbed estuary: The role of detrital and algal resources. PNAS. 99: 8101-8105.

Sate Water Resources Control Board. 2000 Water Quality Management Plan. Protest Dismissal Agreement between CCWD and Delta Wetlands Properties, Exhibit B. October.

United States Geological Survey. 1998. Dissolved organic carbon concentrations and compositions, trihalomethane formation potentials in water from agricultural peat soils, Sacramento-San Joaquin Delta, California: Implications for drinking water. Water resources investigation report 98-4147. Sacramento, CA: 75 p.

United States Geological Survey. 2001. Improving water quality in Sweetwater Reservoir, San Diego County, California: Sources and mitigation strategies for trihalomethane (THM)-forming carbon. USGS Facts Sheet 112-01. Sacramento, CA: 9p.

Chapter 4: SIMULATION OF TEMPERATURE AND DISSOLVED OXYGEN

4.1 Introduction

A series of DSM2 daily planning studies were run in HYDRO and QUAL using the proposed operations for the IDS project islands. The objectives of these studies were to understand the impacts of the In-Delta storage reservoirs in the dissolved oxygen (DO) and temperature of the Delta channel systems and urban intakes. All of the operation scenarios were simulated with the CALSIM II Daily Operations Model (DOM). Of several CALSIM runs only two studies were used in the DO and temperature studies. A basic description of the DSM2 / CALSIM II scenarios and their identification is listed in Table 4.1.

Table 4.1: DSM2 and CALSIM study scenarios

DSM2 Study	CALSIM II Study	Description
Study 1 (Base)	Study 1	No IDS project islands
Study 2 (Alt 1)	Study 3a	IDS project islands w/ no DOC constraints

4.2 Modeling Approach

Simulation of DO by DSM2 requires information on water temperature, BOD, chlorophyll, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, organic phosphorus, and dissolved phosphorus (ortho-phosphate) in the Delta. In order to simulate DO, a group of related variables has to be simulated at the same time. A conceptual model showing the interaction among water quality variables in DSM2 model is shown in Figure 4.1. The location of project islands and the island release points as modeled in the DSM2 model is shown in Figure 4.2.

In Figure 4.1, the rates of mass transfer (shown by the arrows) are functions of temperature. It is important that temperature simulation be included in the DO simulation. The sources and sinks of DO are indicated in Figure 4.1. Further information on DSM2 kinetics is given in a 1998 report by the Department of Water Resources (Rajbhandari 1998), also available at the Delta Modeling Section web site http://modeling.water.ca.gov/delta/reports/annrpt/1998/chpt3.pdf. Recent work on calibration and validation of DSM2 for DO is documented in Rajbhandari et al (2002). The conceptual and functional descriptions of constituent reactions represented in DSM2 are based generally on QUAL2E (Brown and Barnwell 1987), and Bowie et. al (1985). The DO concentration in the island reservoir(Figure 4.1) is both a function of the mixing associated with diversions to the islands, changes due to growth, decay and mass transformations, oxygen demand associated with the peat soils, wind effects, and stratification. DSM2 can be used to model all of the effects except for stratification.

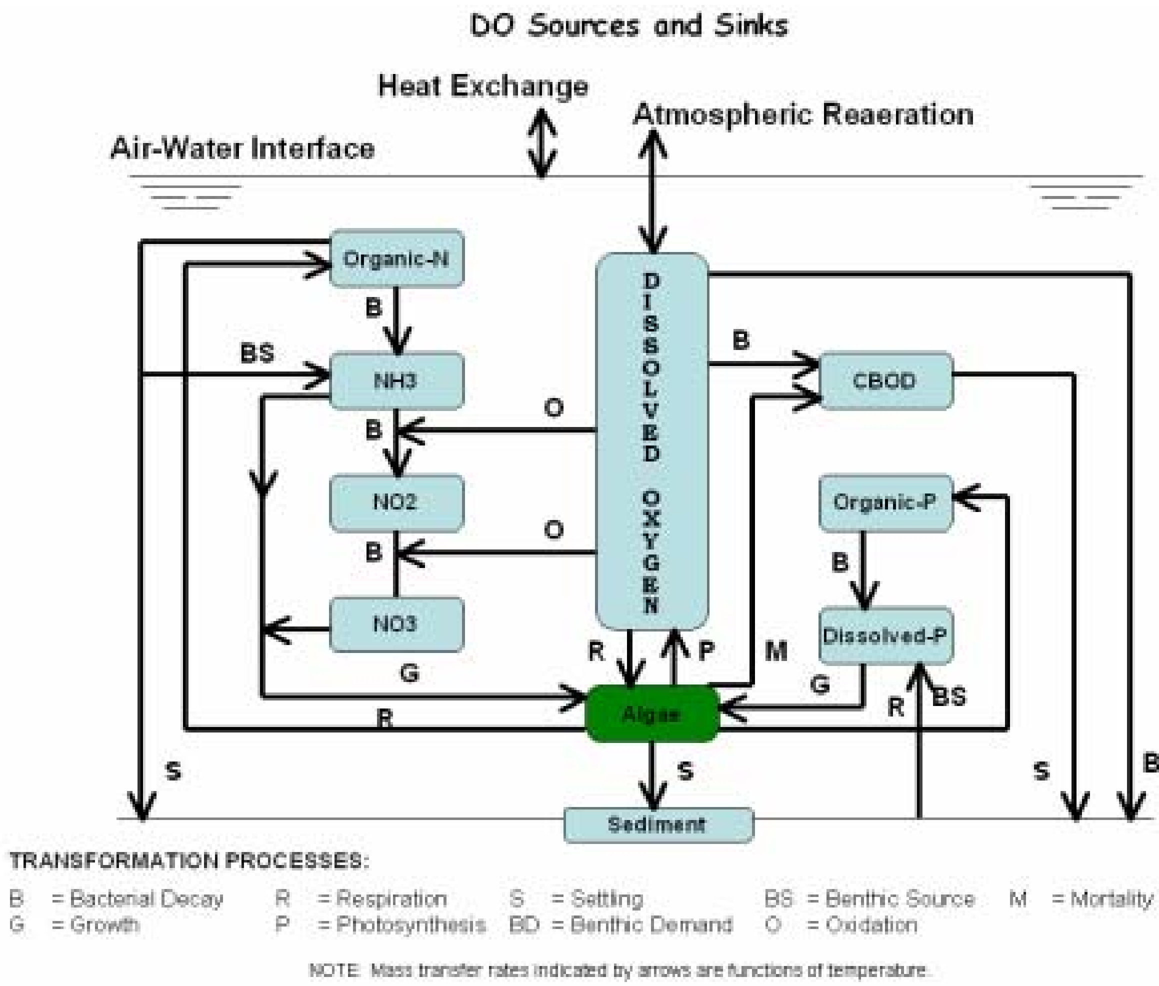


Figure 4.1: DO and Interaction among Water Quality Parameters

Data collected at hourly intervals for DO and temperature provides boundary information needed by DSM2. Estimated DO data in Sacramento River at Freeport were provided for the Sacramento River model boundary. The historical record of DO and temperature, available from May 1993 at Martinez including estimates for missing data, was used for the downstream boundary. The estimates were based on extrapolations of 1997-2000 data, averaged to daily averages, and extended to 1975-1983. Since continuous data were not available at Vernalis (RSAN112), hourly values of DO and temperature available from the nearby station at Mossdale (RSAN087) were used to approximate these quantities for the boundary inflow at Vernalis. For 1975-1983, estimates based on extrapolation of data were used. Since the flows at Vernalis are primarily unidirectional, and the hydraulic residence time is relatively short, this assumption seems appropriate.

Nutrient data at Vernalis were approximated from the San Joaquin River TMDL measurements sampled at weekly intervals in 1999. The nutrient data at Freeport on the Sacramento River were approximated from the latest publication of the U.S. Geological Survey report (USGS 1997) and chlorophyll data were approximated from the statistical analysis study by Nieuwenhuyse, 2002.

Estimates of flow and water quality of agricultural drainage returns at internal Delta locations were based on earlier DWR studies. Estimates of data were also based on other sources such as Jones and Stokes (1988).

Climate data at hourly or 3-hour intervals representing air temperature, wetbulb temperature, wind speed, cloud cover, and atmospheric pressure (source: National Climatic Data Center) provided DSM2 input for simulation of water temperature. An electronic version of the data was available only from 1997. Data from 1997-2000 were extrapolated to cover the 16 years period from 1975-1991.

Model simulations were based on 15 minute time-steps. However analysis of model results was based on daily averaged values because hydrodynamics information was based on daily averaged values, and several water quality boundary conditions were based on daily averaged values.

4.3 Project Island DO and Temperature

As explained earlier, the concentration inside either island (see, Figure 4.1) is both a function of the mixing associated with diversions to the islands, changes due to growth, decay and mass transformations, oxygen demand associated with the peat soils, wind effects, and stratification. DSM2 modeled all the effects except for stratification. Therefore, the model results discussed below applies to the case where the stratification effects are negligible. A sediment oxygen demand of about 2 $g/m^2/day$ was used, primarily to maintain a minimum DO of 5 mg/l in the islands. To account for other oxygen consuming organic load that may not be accounted for including stratification effects, island DO was maintained at 5 mg/l, thus giving some allowance for uncertainties (about 15 %, because reservoir DO actually needs to be at 6 mg/l. or above).

One significant assumption is that DSM2 simulates reservoir as completely mixed. Also, water stored in the reservoirs has initially very low organic load, since these reservoirs are filled in from the channels.

4.4 DO and Temperature Requirements

The following DO and temperature constraints were utilized in evaluating the studies:

DO: Discharge of stored water is prohibited if the DO of stored water is less than 6.0 mg/L, if discharges cause the level of DO in the adjacent Delta channel to be depressed to less than 5.0 mg/L, or if discharges depresses the DO in the San Joaquin River between Turner Cut and Stockton to less than 6.0 mg/L September through November.

Temperature: Discharge of stored water is also prohibited if the temperature differential between the discharge water and receiving water is greater than 20º F, or if discharges will cause an increase in the temperature of channel water by more than: 4º F when the temperature of channel water ranges from 55º F to 66º F, 2º F when the temperature of channel water ranges from 66º F to 77º F, or 1º F when the temperature of channel water is 77º F or higher.

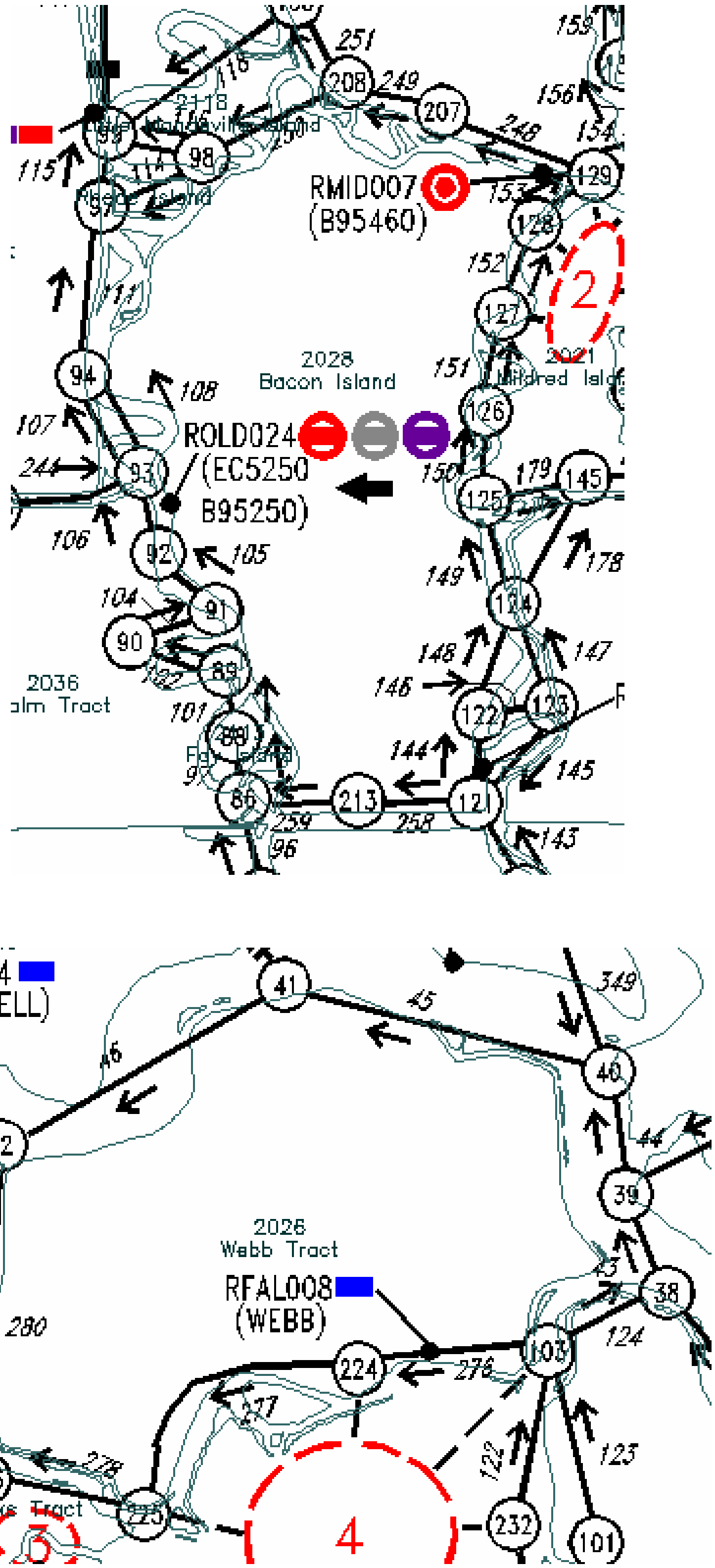


Figure 4.2: Representation of Webb Tract and Bacon Islands in DSM2

4.5 Discussion of Model Results

4.5.1 DO Near the Islands

Near project island DO are shown in Figures 4.3. For the sake of clarity the 16 year simulation time series plots are broken into four plots of equal time period. In Figure 4.3, 276 refers to the channel near Webb tract; 128 indicates release node at Bacon. For all alternatives, the plots show no violation, since the DO is never depressed to below 5 mg/l. The highest depressions seem to be at Node 128 near Bacon, during July of 1981 and 1982 by almost 2 mg/l.

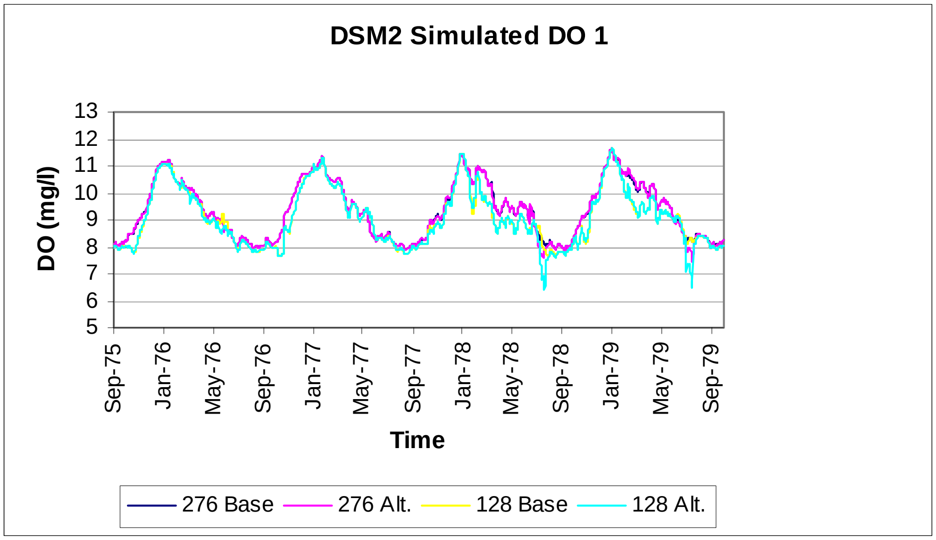


Figure 4.3a: Concentration of DO for Different Alternatives for WY 75-79

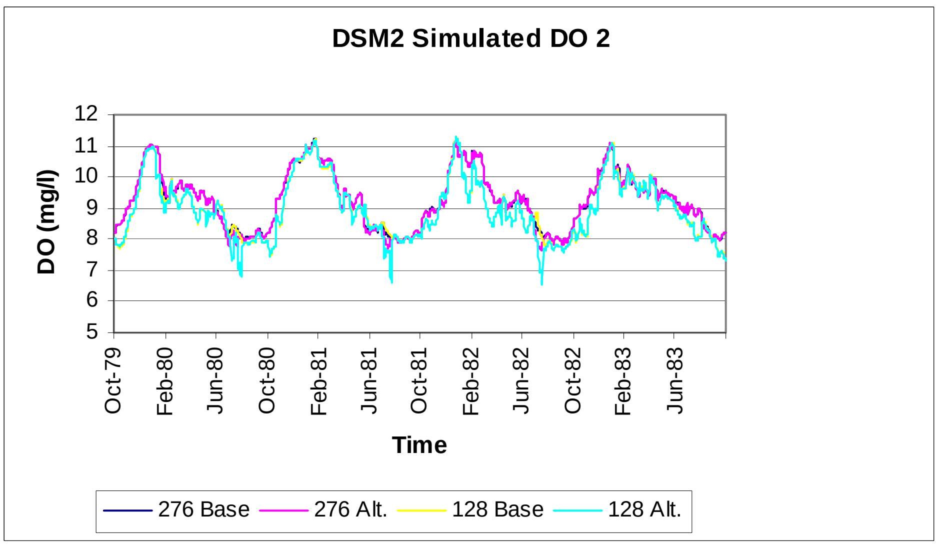


Figure 4.3b: Concentration of DO for Different Alternatives for WY 79-83

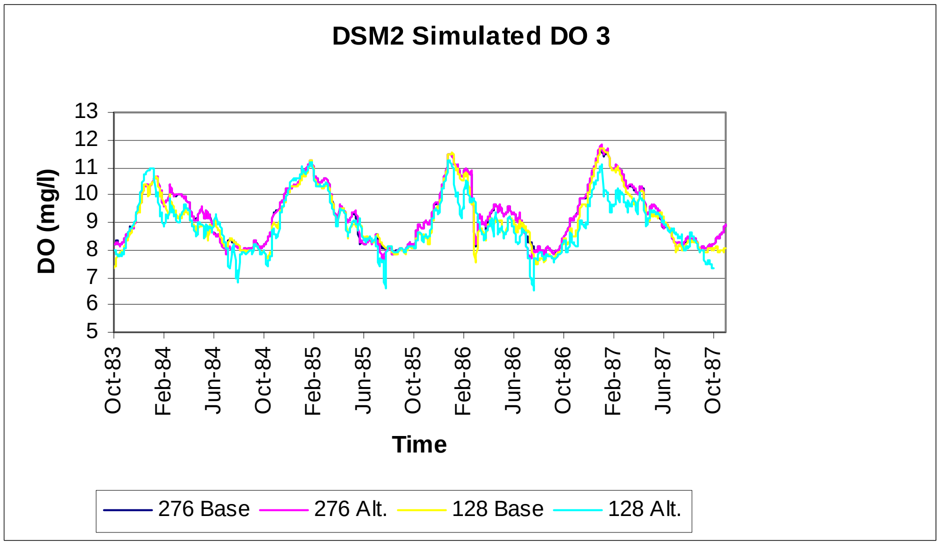


Figure 4.3c: Concentration of DO for Different Alternatives for WY 83-87

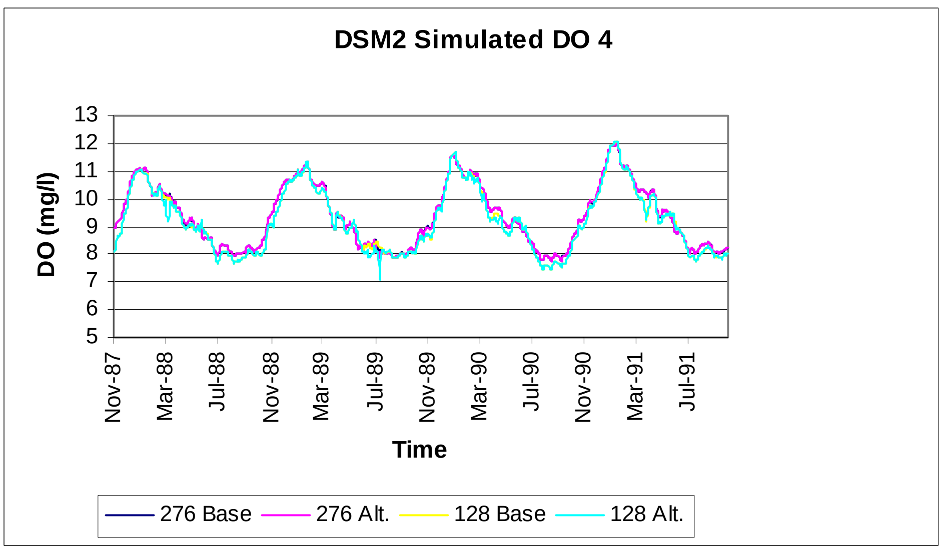


Figure 4.3d: Concentration of DO for Different Alternatives for WY 87-91

4.5.2 Temperature Near the Islands

Channel water temperature for base and alternative scenarios are shown in Figures 4.4 a through d. In Figure 4.4, 276 refers to the channel near Webb Tract; 213 indicates release node at Bacon (see Figure 4.2 for release locations); "a" refers to base scenario, and "b" refers to Alt-1 study. For temperature plots near Bacon Island, another location (i.e., node 213) was used because it showed a higher temperature differential than for than for node 128.

The plots show some violations. These violations only occur for temperatures that are higher than 77 degrees, when the one degree or lower differential requirement applies. The highest violations occur in channel near Bacon (node 213). There were a total of 16 days of violations in 16 years based on daily average model results (see the table shown below).

Only two days of violation by about 1 degree occurred during July 14-15, 1979 for the channel near Webb (276). A summary of the incidences of violations periods for both islands are given in Table 4.2.

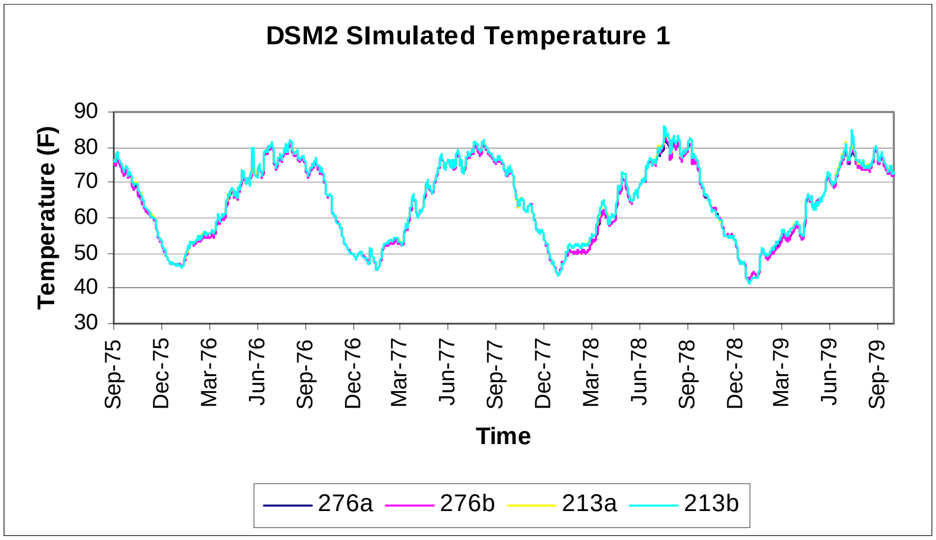


Figure 4.4a: Channel Water Temperature from Different Alternatives for WY 75-79

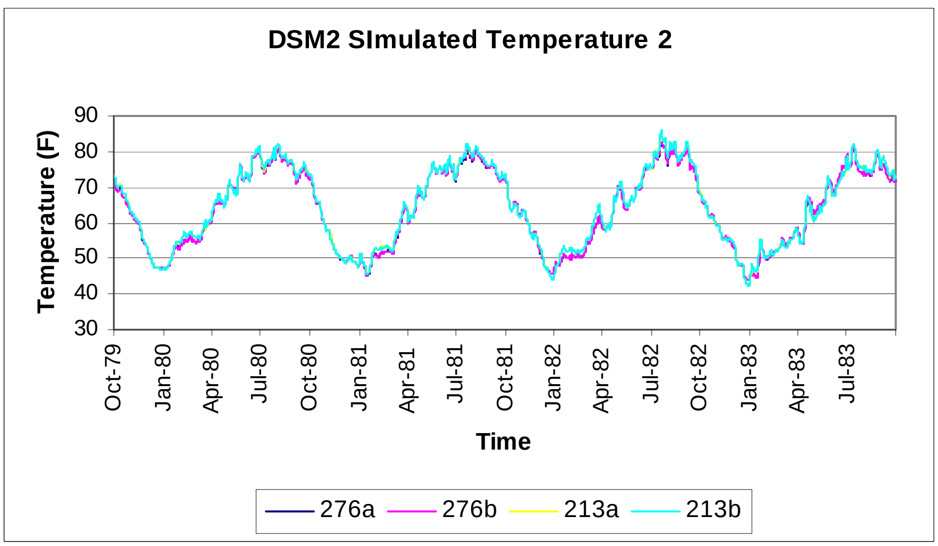


Figure 4.4b: Channel Water Temperature from Different Alternatives for WY 79-83

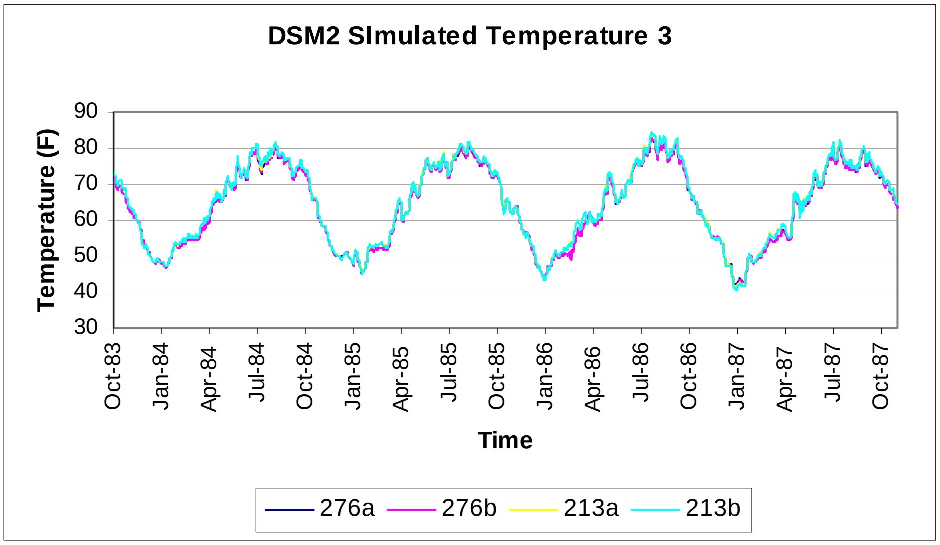


Figure 4.4c: Channel Water Temperature from Different Alternatives for WY 83-88

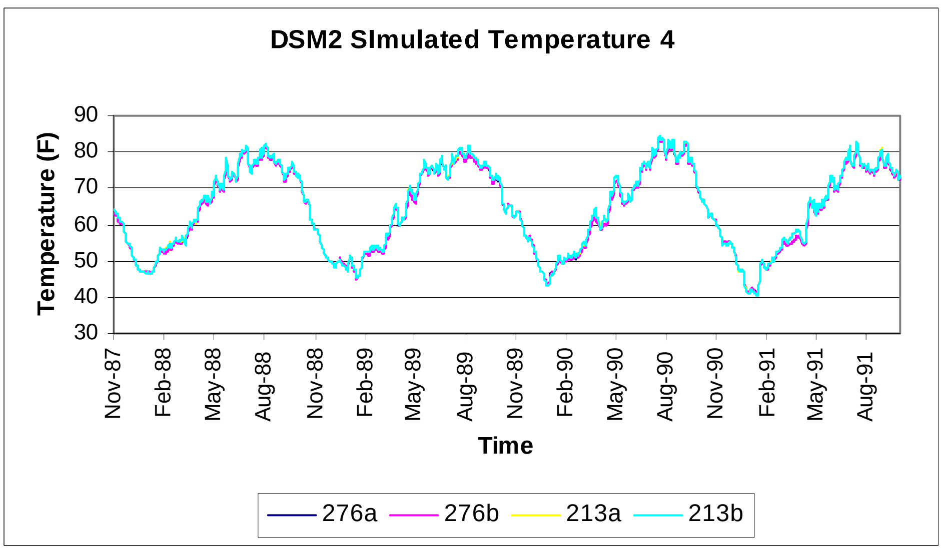


Figure 4.4d: Channel Water Temperature from Different Alternatives for WY 87-91

Table 4.2: Summary of Violation Period in Water Temperature

Island near Release	Violation (degree, F) in Channels near Discharge	Time Period
Bacon	~2	May 23-24, 1976
Bacon	1-2.5	July 11-14, 1978
Bacon	1-2.5	July 16-20, 1978
Bacon	1-2.5	July 17-21, 1982
Webb	~1	July 14-15, 1979

4.6 Conclusions

Based upon the DSM2 studies of DO and temperature, the following conclusions could be inferred.

- DSM2 modeling indicates that for the Alt-1 operations DO conditions will not be violated. It was assumed that the island DO levels would not fall below 6 mg/l as required. A few days violations could occur for the temperatures that are higher than 77 degrees. The model results were based on daily averaged values.
- Water quality data needed for boundary conditions for the planning study were based on extrapolation of available data, when historical data were not available.
- Model simulation did not indicate that differences in water temperature between the island and the channel would exceed 20 degrees.

4.7 References

Bowie, G.L., W.B. Mills, D.B. Porcella, C.L. Campbell, J.R. Pagenkopt, G.L. Rupp, K.M. Johnson, P.W.H. Chan, and S.A. Gherini. (1985). *Rates, Constants and Kinetics Formulations in Surface Water Quality Modeling, 2nd Ed.* US EPA. Athens, Georgia. EPA 600/3-85/040.

Brown, L.C. and T.O. Barnwell. (1987). *The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS; Documentation and Users Manual*. US EPA. Athens, Georgia. EPA 600/3-87/007.

California Department of Water Resources. (1999). *Water Quality Conditions in the Sacramento-San Joaquin Delta during 1995.* Div. of Local Assistance.

Jones & Stokes Associates. (1998). *Potential Solutions for Achieving the San Joaquin River Dissolved Oxygen Objectives*. Prepared for De Cuir & Somach and City of Stockton Department of Municipal Utilities.

Mierzwa, M. (2003). "Summary of DSM2 In-Delta Storage (IDS) Planning Study" Technical memo (DRAFT) dated July 18, 2003. California Department of Water Resources. Sacramento, CA.

Nueuwenhuyse, E.E.V. (2002). *Statistical Model of Dissolved Oxygen Concentration in the San Joaquin River Stockton Deepwater Channel at Rough and Ready Island, 1983-2001.* Submitted to the San Joaquin Dissolved Oxygen TMDL Technical Advisory Committee.

Rajbhandari, H. L., P. Nader and P. Hutton. (2002). *DSM2 Studies to Investigate the Use of Auxiliary Flow Pumps across South Delta Flow Structures*. Report to San Joaquin River Dissolved Oxygen TMDL Stakeholder Process Technical Advisory Committee. CALFED Directed Action Project.

Rajbhandari, H.L. (2003). "Chapter 3: Extending DSM2 QUAL Calibration of Dissolved Oxygen". *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 24th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

Rajbhandari, H.L. (1998). "Chapter 3: DSM2 Quality". *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 19th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

US Geological Survey. (1997). "Water Resources Data, California, Water Year 1997." Vol. 4.